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Vegetation colonization within exposed reservoirs following dam removal on the Elwha River, Washington

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Vegetation Colonization within Exposed Reservoirs Following Dam Removal on the Elwha River, Washington

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ABSTRACT

Riparian ecosystems are important for ecological functioning of rivers, and are significantly impacted by dams. With over 50% of large dams in the U.S. beyond their life expectancy, dam removal is increasingly being considered to eliminate aging infrastructure and restore ecosystems. There have been few large dam removals to date, so studies assessing vegetation succession on exposed reservoir sediments are limited. My research aims to assess how environmental factors within exposed reservoirs affect vegetation succession following removal of two dams on the Elwha River, Washington. In addition, I compared patterns of vegetation among the two reservoirs and their landforms. To do this, I sampled 67 100 m^2 plots in 2013 and 60 100 m^2 plots in 2014 along 10 transects within Mills and Aldwell Reservoirs. In each plot, I recorded vascular plant species composition and woody species height. I collected and pooled 8 soil samples (20 cm) / plot to assess percent organic matter, nutrients, and percent sand, silt, clay, and conducted a Wolman Pebble Count. I used a structural equation models to show how environmental factors related to hydrology, soil nutrients, and dispersal distance affect species diversity and cover. I compared environmental factors and vegetation responses among the two reservoirs using general linear models.

Structural equation models showed that soil nutrient levels, sediment texture, ground cover, and landform were the environmental factors most related to reservoir revegetation patterns. Native species richness and cover, and exotic species cover were highest on valley walls and were positively related to high percent organic matter and % silt, but negatively related to % litter, D50, Mg, and P. In contrast, exotic richness was highest on terrace and riparian landforms with low % litter, Mg, and P and high % organic matter that were furthest away from established forest communities. Sediment nutrient indicator variables organic matter, Mg, and P were co-correlated with other sediment variables and act only as a surrogate for those variables in these models.

In total, 147 vascular plant species were sampled in the two reservoirs of which 47 (31%) were exotic. Aldwell reservoir contained higher native and exotic species richness, cover, and woody species growth, and had finer textured sediments, deeper

sediment depth to refusal, and higher % litter ground cover than Mills reservoir in 2013, while Mills reservoir had higher % gravel ground cover. By 2014, the only significant difference between reservoirs was woody species height, which was higher in Aldwell reservoir. Native species richness and cover were higher than that of exotic species in both reservoirs; however, exotic species are increasing, particularly along riparian zones within both reservoirs and on the most fertile sites along Aldwell valley walls and terraces. The increase in exotic species occurred despite active management to control them, and should be a concern to Olympic National Park because the reservoirs could become a gateway of exotic species invasion into a relatively protected landscape.

Over time, I expect multiple vegetation communities to form within each reservoir associated with landform. Valley walls will likely return to the composition and structure of surrounding upland forests, while riparian zones will likely come to resemble the upstream Elwha River reaches not affected by damming. Terraces, on the other hand, will likely form novel vegetation communities dependent on environmental factors that will differ between the two reservoirs.

The results of my study highlight the effect of varying environmental conditions on vegetation recovery rates and can help inform the Elwha River restoration project as well as any future dam removal projects.

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INTRODUCTION

Riparian zones are diverse, dynamic systems that provide habitat for fish and wildlife, filter contaminants, and act as plant dispersal corridors (Naiman et al. 1993, Naiman and Decamps 1997). Riparian ecosystems are highly adapted to the natural flow regimes of the river they are formed around (Poff et al. 1997, Nilsson and Berggren 2000, Poff and Zimmerman 2010). The damming of rivers drastically alters riparian system functions by altering flow regimes, limiting habitat, and impairing filtering ability between upland and aquatic systems (Dynesius and Nilsson 1994).

Dams can negatively impact plant dispersal by trapping seeds and sediment within their reservoirs, contributing to reduced vegetation diversity within the riparian community (Jansson et al. 2000, Brown and Chenoweth 2008). With over 50% of large dams in the US beyond their 50 year life expectancy, dam removal is increasingly being considered to eliminate aging infrastructure and restore ecosystem functions (National Inventory of Dams, Hart et al. 2002, The Heinz Center 2002, and American Rivers 2014).

Relatively few studies have considered the effects of dam removal on vegetation recovery within exposed reservoirs (Lenhart 2000, Shafroth et al. 2002, Orr and Koenig 2006, Orr and Stanley 2006, Auble et al. 2007, Chenoweth 2007, Chenoweth et al. 2011, Michell et al. 2011, Whisman 2013); so it is unknown whether vegetation recovery within exposed reservoirs will follow linear succession back to pre-dam community, create novel communities dependent on site, or have no natural revegetation and therefore require management.

Benefits of established vegetation in newly drained reservoirs include stabilization of sediments (Mussman et al. 2008), return of wildlife habitat, and human recreation (AR/FE/TU 1999). However, in some cases, unfavorable site conditions could lead to very little vegetation recovery. Also, if invasive plant species colonize and dominate following dam removal, they could have profound long-term effects on vegetation succession (Vale 1988, Hobbs and Mooney 1993, Davis et al. 2003, Lockwood and Samuels 2004, Young et al. 2005, Hobbs et al. 2009). Understanding initial natural vegetation recovery will help land managers know where active management is required, such as sites without natural revegetation or sites conducive to exotic species colonization.

On the Elwha River, past studies on dredged reservoir sediments suggest that native vegetation will be able to successfully recolonize exposed reservoir sediments (Chenoweth 2007), but germination rates on dredged reservoir sediment were shown to be about 15 % less successful than those on alluvial sand (Michel et al. 2011). Exotic species have been shown to successfully germinate on fertile exposed reservoir sediments in a small dam removal study in Wisconsin (Lenhart 2000, Orr and Koenig 2006) and if established first, high abundances of non-native species can negatively influence native species richness and cover (Lenhart 2000, Orr and Stanley 2006).

Initially established vegetation communities were shown to have changed frequently on exposed sediments during the first four years or recovery following the Horsetooth Dam removal in Colorado. Short lived species colonized exposed sediment first with perennials increasing over time. Substantial shifts in dominant species, both native and non-native, were also observed as conditions changed from mesic to xeric and as the species composition increased in similarity to surrounding upland composition (Auble et al. 2007).

The uncertainties of vegetation recovery in exposed reservoirs led Orr and Stanley (2006) to hypothesize three trajectories most likely to occur following dam removal. Their first hypothesized trajectory was that species compositional change over time would be predictable and follow classic primary succession. Their second hypothesized trajectory was that dam removal would create conditions conducive to the establishment of exotic species. Their last hypothesized trajectory, similar to Gleason's (1926), was that plant establishment and species composition would relate to site-specific-attributes.

Site-specific attributes that may affect natural vegetation restoration following dam removal include distance to and composition of nearby plant communities (and, thus, seed sources). Nearby plant communities typically influence the composition of colonizing plant species, and over-time vegetation communities within the reservoirs may come to resemble surrounding upland or riparian communities depending on site-specific attributes such as sediment moisture, sediment depth, sediment texture, sediment pH, elevation above the river, and nutrient availability (McCook 1994, Nekola and White 1999, Bendix and Hupp 2000, Walker and del Moral 2009, Chenoweth et al. 2011; Fig. 1.1).

The amount of time following sediment exposure is also thought to play a key role in driving vegetation patterns, because it allows geomorphic and vegetation successional processes to occur (Hupp and Osterkamp 1985, Latterell et al. 2006). Differences in geomorphology have been found influence patterns in plant diversity (Burnett et al. 1998; Brown and Peet 2003), suggesting that the environmental and geomorphic diversity found within drained reservoirs could also have a strong effect on colonizing plants. Different vegetation communities are associated with different geomorphic features, and as impoundments become more geomorphically diverse they should also become more vegetatively diverse (Hupp and Osterkamp 1985; Fig. 1.1). After the remaining reservoir sediment is incised by the river. Over several decades, an equilibrium channel should form with new floodplains, terraces, active channel shelves, and depositional bars (Pizzuto 2002). Novel geomorphic surfaces such as high terraces could also form as the reservoir drains.

Sediment fill within reservoirs could be incised in a variety of ways depending on the height of the sediment fill and its grain size (Pizzuto 2002). Impoundments containing finer textured clay and silt sediments are likely to erode by a vertical headcut (an eroding vertical face in the stream bed) moving upstream through the fill (Doyle et al. 2002, O'Connor et al.2015). Coarse-textured sand sediments are likely to erode through groundwater sapping or other mass wasting processes related to liquefaction (saturated sandy sediments lose strength and behave as a viscous liquid rather than as a solid); it is also possible that a knickpoint (an abrupt change in slope) could form and move upstream through sandy sediments. Sediment containing high amounts of gravel will likely only be incised during high-flow events (Doyle et al. 2002).

After dam removal the original valley walls that were formerly inundated by a reservoir will become exposed. The newly exposed valley walls will be the only landform that was present prior to the damming of the river and are expected to remain relatively stable through the river incision process (Fig. 1.1). However, reservoir sediments can differ in their physical and chemical properties from pre-dam soils, which may influence vegetation restoration and exotic species colonization (DOI 1996, Chenoweth et al. 2011). Over time, colonizing vegetation communities on the valley walls should begin to resemble surrounding upland plant communities. Populations of returning vascular plants should recover to their original pre-dam levels prior to forest canopy closure, but in typical forest succession, pre-dam diversity levels can take more than two decades to return after canopy closure (Halpern and Spies 1995).

Vegetation communities established along the floodplains, active channel shelves, and depositional bars will likely be affected by fluvial processes. These riparian zones are transient features where the geomorphic structures and vegetation community composition are determined by lateral river channel movements (Latterell et al. 2006). Flooding can deposit water dispersed seeds (hydrochores) along bars and active channel shelves, while high flow events can scour the bars and shelves exposing sediment for colonization and deposit hydrochores onto the floodplains (Hupp and Osterkamp 1985; Fig. 1.1).

Initial vegetation colonization along terraces will likely be affected by dispersal from surrounding upland plant communities and wind dispersed seeds (anemochory) (McCook 1994, Walker and del Moral 2009; Fig. 1.1). As plants colonize the bare substrate along the high terraces, soils will begin to develop (Acker 1990) and easily erodible sediments will stabilize. Over time, vegetation communities could possibly become similar to surrounding upland vegetation communities or turn into novel plant communities. But, initially plants established on the reservoir terraces are expected to face wind and sun desiccation, which may limit available sediment moisture.

Other factors on exposed reservoir surfaces that may influence sediment moisture necessary for plant growth include sediment texture, sediment depth, and elevation above the river. Fine textured (silt/clay) sediments with stable granular structure should retain water available to plants after rainfall or flooding events (Barbour et al. 1980). Such sediments without stable granular structure could retain water so strongly that it is unavailable to plants (Brady and Weil 2009) and may inhibit root growth (Naiman et al. 2005). Coarse textured (sand) sediments contain large macropore spaces which may not retain water available to plants (Henderson et al. 1989, Naiman and Decamps 1997, Brady and Weil 2009). Consequently, plants are more prone to experience drought conditions in sandy substrate than in silt (Chenoweth 2007, Brady and Weil 2009, Wishman 2013). Sediment depth and elevation above the river could further limit water availability by increasing the distance to the water table, possibly favoring deep rooted or drought tolerant exotic species during initial revegetation (Stromberg et al. 2007, Fig. 1.1).

At first, in drained reservoirs it may be hard to determine how nutrient availability relates to sediment texture because dewatered reservoirs may contain inorganic sediments (Chenoweth et al. 2011); or alternatively, they could contain overly organic sediments because, when formed, the reservoirs inundated plant communities such as forest floors (Draut and Ritchie 2015). However, the relationship between sediment texture and nutrient availability is expected to become an important factor for vegetation colonization within drained reservoirs as soil structure develops over time (Brady and Weil 2009).

Nutrient availability necessary for plant establishment, diversity, and growth is also thought to relate to sediment texture (Fig. 1.2). Finer textured sediments from the Elwha River were found to contain greater concentrations of Fe, P, C, and N than coarser textured sediments (Cavaliere and Homann 2012). Finer textured sediments were also found to support more plant biomass than coarser textured sediments due to amounts of N, P, and moisture present (Cavaliere and Homann 2012, Asaeda and Rashid 2012).

As vegetation cover increases in exposed reservoirs, nutrient availability is also expected to increase, due to organic matter input to the sediment and because transpiration may become high enough on the bars, active shelves, and floodplains to increase mass flow of nutrient solutes towards plant root systems (Naiman and Decamps 1997). Greater vegetation cover will also decrease nitrate and phosphorus loading (Young-Matthews et al. 2010) which otherwise can negatively affect plant growth (Ye et al. 2012). However, it is still unclear how quickly colonizing plant roots will become proficient in extracting nutrients from the newly exposed sediments and in which substrate establishment will mostly readily occur; if plants are unable to extract nutrients at sufficient rates (Cavaliere and Homann 2012), active management may be required to establish vegetation .

Sediment pH can also affect nutrients and be informative of their chemical and biological conditions. pH affects the availability of nutrients in soils and the osmotic potential of plant roots absorbing the nutrients from soil solutions. In strongly acidic conditions, macronutrients such as Ca, Mg, K, P, N, S, and micronutrient B may not be readily available to plants; and Al, which is not a plant nutrient, can increase to toxic levels (Brady and Weil 2009). In slightly acidic conditions, nutrients such as Fe, Mn, Zn, Cu, and Co can become readily available, but they are most available in slightly alkaline conditions. Phosphorus will likely be most available to plants at neutral pH (Brady and Weil 2009). One study comparing drained reservoirs on the Elwha River found sediment pH was negatively correlated with tree coverage was the only consistent result between both reservoirs (Werner 2014).

Dam removal along the Elwha River, WA

The removal of the Elwha and Glines Canyon dams (2011-2014) along the Elwha River in Washington State (Fig. 1.3) were among the largest dam removal projects to date (O'Connor et al. 2015), and present an excellent opportunity to study how time, geomorphology, and site-specific environmental characteristics affect natural vegetation recovery. The Elwha and Glines Canyon dams were built without fish ladders in the early 1900's and were removed in accordance with the 1992 Elwha River Ecosystem and Fisheries Restoration Act (Public Law 102-495) in an attempt to fully restore ecosystem functions and native anadromous fisheries.

Few disturbances compare to the removal of the Glines Canyon and Elwha dams in terms of creating a large scale model for studying primary and secondary plant succession, aside from volcanic eruptions (del Moral e al 1995) or glacial events (Acker 1990). This project provides a rare opportunity to compare natural vegetation recovery within two ecologically different reservoirs in the same watershed, which could allow researchers to make predictions about similar processes on other reservoirs.

Researchers at Olympic National Park (ONP) have been monitoring naturally established vegetation on valley walls and terraces within 24 plots in Mills reservoir and 9 plots in Aldwell reservoir as part of their Elwha reservoir revegetation project. Results showed that Aldwell reservoir contained more species with a higher percentage of exotics than Mill reservoir in 2013. Plant cover, survival, growth rates, species richness, sapling densities, and seedling densities were all highest on finer sediment sites in contrast to coarse sediment sites, suggesting sediment texture may be one of the strongest factor influencing natural plant succession within the reservoirs (J. Chenoweth, National Park Service, unpublished report, Calimpong 2013). While the findings show a higher return of native species, this study did not conduct nutrient analyses and had limited numbers of sample sites that were surveyed only the first year following removal.

Another one year study conducted in 2013 (Werner 2014) compared 40 valley wall plots between Aldwell and Mills, finding that vegetation cover was positively correlated with N, K, and organic matter, and negatively correlated with P. Aldwell reservoir valley walls contained higher levels of N, K, organic matter, and lower sediment pH than Mills reservoir which had higher levels of P. Werner (2014) concluded that vegetation recovery along Mills valley walls will likely be influenced by water availability, P, N, % organic matter, and sediment pH. Findings also showed that exotic species cover was positively correlated with species cover within both reservoirs indicating that exotic species are growing in the most fertile sediments. This study did not examine revegetation on terrace or riparian landforms within the reservoir. Werner's (2014) results were consistent with another study by Cavaliere and Homann (2012) of reservoir sediments pre-dam removal which found that Aldwell reservoir contained finer sediment and higher nutrient levels than Mills.

Objectives

The overall objective of my two year study was to assess how environmental characteristics such as distance to forest, sediment depth to refusal, sediment texture, sediment pH, and nutrient availability influence establishing vegetation communities across the range of landforms found within both reservoirs. In contrast to the previous studies on the Elwha reservoirs, this study included riparian landforms, which had not previously been sampled, and was sampled over two years. In addition, soil nutrients and texture were measured on all landforms. My study connects sediment characteristics along valley walls, terraces and riparian landforms to species richness, species cover, and woody species growth rates (Bendix and Hupp 2000, Chenoweth et al. 2011, Werner 2014, J. Chenoweth, National Park Service, unpublished report).

My study included two components. First, I specifically tested the hypothesis that sediment nutrients, texture, and depth, ground cover, reservoir location, and dispersal distance would be related to species richness and woody vegetation growth using structural equation models. Second, I tested the hypothesis that Aldwell reservoir, which had been shown to have finer sediment, would have higher levels of species richness, cover, and woody species growth than Mills reservoir; and that valley wall landforms would have higher richness, cover and growth than terraces or riparian landforms. In addition, I expected that valley wall sediment would be finer and more fertile than the more recently deposited alluvial sediments of terraces and riparian landforms. I also predicted that when comparing the two reservoirs, valley wall landforms would have the most similar plant species richness, cover, and woody species height.

METHODS

Study Area

The Elwha River is located on the Olympic Peninsula and flows 80 km north from the Olympic Mountains to the Strait of Juan de Fuca near Port Angeles (Munn et al.

1999). The Elwha River drainage is more than 699 km^2 with 83% of that area within Olympic National Park (Munn et al. 1999). The mean annual flow of the Elwha is 42.7 m^3 per second (BOR 1996). The upper reaches of the river receive approximately 560 cm annual precipitation while the lower reaches receive about 142 cm annual precipitation (Duda et al. 2008).

Both dams were located near the mouth of the river leaving 58.4 river km of high quality upstream area intact within the Olympic National Park (O'Connor et al. 2015). The 33 m high Elwha Dam, at river kilometer 7.9, was completed in 1913 and formed Lake Aldwell (Duda et al. 2008). Lake Aldwell was 4.5 km long, 0.4 km wide, had a maximum depth about 30 m, and inundated 1.07 km^2 of now exposed sediments (Chenoweth et al. 2011). The 64 m high Glines Canyon Dam placed at river kilometer 21.6 was completed in 1927 and formed Lake Mills (Duda et al. 2008). Lake Mills was 4 km long, 0.8 km wide, had a maximum depth about 60 m, and inundated 1.77 km^2 of now exposed sediment (Chenoweth et al. 2011). Mills reservoir receives 178 cm of precipitation while Aldwell reservoir receives 127 cm of precipitation annually (Chenoweth et al. 2011). Dam removal began in September 2011, with the Elwha Dam fully removed by March 2012 and the Glines Canyon Dam fully removed by September 2014. When this study began, in July 2013, 16 m of the Elwha dam still remained, however the reservoir had been drained with pooled water completely gone by June 2012 (J. Chenoweth, personal communication, May 12, 2015).

Approximately 21 to 26 x 10^6 m^3 of sediment had accumulated behind the Glines Canyon and Elwha Dams. The upstream reservoir, Mills, stored approximately 21.6 ± 3.0 10^6 $m^3$of sediment, while Aldwell, stored approximately 4.6 ± 1.5 10^6 m^3 sediment

(Draut and Ritchie 2015). It was estimated that two-thirds to one half (Draut and Ritchie 2015) of the total sediment volume would remain in the reservoirs for the first five years post dam removal, and that the remaining sediment would be composed of 50% clay/silt sized particles and 85% coarser sand sized particles (DOI 1996). The depth of the sediment in Mills reservoir is estimated to be between 6 and 12 m, with high terraces up to 18 m (Chenoweth et al. 2011, Calimpong 2013). The depth of the sediment in Aldwell reservoir is estimated to be between 2.5 and 5.5 m, with high terraces up to 9 m (Chenoweth et al. 2011, J. Chenoweth, National Park Service, unpublished report).

Aldwell reservoir is surrounded by a matrix of managed forest land and consists of diverse vegetation types. Dominant species in the managed forests include red alder (*Alnus rubra*) and large cottonwoods (*Populus spp*.). Understory plants include salmonberry (*Rubus spectabilis*), slough sedge (*Carex obnupta*), skunk cabbage (*Lysichiton americanus*), and jewelweed (*Impatiens sp*.). The unmanaged forest immediately surrounding Aldwell reservoir ranges from 40 to 120 years old and is dominated by Douglas-fir (*Pseudotsuga menziesii*), bigleaf maple (*Acer macrophyllum*), western red-cedar (*Thuja plicata*), and grand fir (*Abies grandis*) with an understory of shrubs, ferns, forbs, and grasess (Chenoweth et al. 2011). High densities of exotic plants occur near the Aldwell delta including reed canarygrass (*Phalaris arundinacea)*, Canada thistle (*Cirsium arvense*), giant knotweed (*Polygonum sachalinense*), Himalayan blackberry (*Rubus discolor*) and common St. John's wort (*Hypericum perforatum*) (Chenoweth et al. 2011, Woodward et al. 2011).

Mills reservoir is surrounded by native conifer forest ranging from 100 to 300 years old. The old growth forest is dominated by Douglas-fir and western hemlock

(*Tsuga heterophylla*) with an understory of western swordfern (*Polystichum munitum*), Oregon grape (*Mahonia spp.*), or Salal (*Gaultheria shallon*). Dominant tree species present include grand fir, big leaf maple, red alder, willow (*Salix spp.*), and cottonwood. Exotic species around Mills reservoir include reed canary grass, Canada thistle, oxeye daisy (*Leucanthemum vulgare*), flat pea (*Lathyrus sylvestris*), herb Robert (*Geranium robertianum*) Scotch broom (*Cytisus scoparius*), common St. John's wort, tall fescue (*Schedonorus arundinaceus*), velvet grass (*Holcus lanatus*), cheatgrass (*Bromus tectorum*), and common timothy (*Phleum pretense;* Chenoweth et al. 2011, Woodward et al. 2011).

Experimental Design

Five transects each were established in both reservoirs. Transects were located perpendicular to the river from reservoir edge to reservoir edge spanning three geomorphic landforms (valley wall, terrace, riparian landforms; Fig. 1.1, Fig. 2.1, Table 2.1). On each transect, 100 m^2 plots were located in a stratified random manner on every major geomorphic feature crossed, with 4 to 12 plots / transect. Geomorphic features were defined by all major breaks in topography or differences in the dominant particle size of surface sediments (Acker et al. 2008). A total of 67 100 m^2 plots were sampled across the 10 transects in 2013. From 2013 to 2014, 8 plots were lost to changing reservoir geomorphology and one plot was added for a total of 60 100 m^2 plots sampled in 2014 (Table 2.2).

Horizontal and vertical positions of transects and plots were determined with a combination of real time kinematic (rtk)-GPS and total station surveying; transects were permanently marked with metal rebar. Plots were located within areas of the reservoir not actively seeded or planted with native vegetation by the Olympic National Park Service.

Vegetation Survey

Within each plot, species identity and percent cover of all vascular plants were recorded at five nested spatial scales (0.01, 0.1, 1, 10, and 100 m^2) using protocols modified from the Carolina Vegetation Survey (Peet et al. 2012). Plots were sampled in July and August of each year. The timing of reservoir drainage varied little among transects, with the exception that terrace landforms at the southern end of Aldwell reservoir were exposed in 2011 while all other landforms sampled were exposed by June 2012 (J. Chenoweth, personal communication, May 12, 2015). Rate of vegetation colonization was determined by the difference in species richness and cover between 2013 and 2014. The height of the tallest representative of each woody species seedling and sapling was recorded in 2013 and 2014; growth rate was determined by the difference in height between the two years.

Environmental Data

In each plot, percent ground cover and coarse sediment grain size were recorded as follows. Percent ground cover of bryophytes and lichens, decaying wood, bedrock/boulder, gravel/cobble, bare sediment, litter, water, and biocrust were visually assessed and recorded for each plot. Wolman pebble counts were conducted within each plot, with 100 measurements each, to assess relative distribution of gravel, cobble, and boulders at the ground surface. Wolman pebble counts were reported as D50, the particle diameter less than or equal to 50% of the particle sizes (Wolman 1954). Sediment depths to refusal were collected at each plot corner and averaged for every plot using a 119 cm soil probe.

To determine sediment nutrient composition, eight 20 cm deep sediment subsamples were collected from the corners and midpoints of edges of each plot and combined into a single pooled sample per plot (Blackwood et al. 2013, Ye et al. 2012). Sediment samples were dried at 60° C for 48 hours (Blackwood et al. 2013) then sent to Brookside Laboratories Inc. in New Bremen, OH for analysis. Sediments were analyzed for percent clay/silt/sand, total cation exchange capacity (CEC), sediment pH, percent organic matter (OM), estimated nitrogen release (ENR), Bray II phosphorous exchange capacity, Mehlich III Extractable P, Bray I P, and the amounts of Mn, Zn, B, Cu, Fe, Al, S, Ca, Mg, K, Na, NO_3-N, and NH_4-N present.

Data Analysis

Reservoir and Landform Comparisons

To determine how ground cover percentages and coarse sediment grain size (D50) varied among reservoirs and landforms over the two years sampled, I used two-way factorial ANOVAs with Tukey's HSD test (RStudio R version 3.1.0 (2014-04-10)).

To compare how total species richness, native species richness, exotic species richness, native species cover, and exotic species cover varied among reservoirs and landforms over the two years I conducted linear mixed effects models using Proc Mixed with the restricted maximum likelihood method (REML) with reservoir, and landform as fixed effects and transect as a random effect (SAS version 9.3, SAS Institute, Inc., Cary, NC; Environmental Systems Research Institute, Inc., Redlands, CA).

To compare change in total species richness, native species richness, exotic species richness, total species cover, native species cover, and exotic species cover among reservoirs and landforms over the two years I conducted linear mixed effects models using Proc Mixed with the restricted maximum likelihood method (REML) with reservoir, and landform as fixed effects and transect as a random effect (SAS version 9.3, SAS Institute, Inc., Cary, NC; Environmental Systems Research Institute, Inc., Redlands, CA).

To compare how woody species height varied among reservoirs and landforms over the two years I conducted linear mixed effects models using Proc Mixed with the restricted maximum likelihood method (REML) with reservoir and landform as fixed effects and transect as a random effect. Prior to analyzing change in woody species height, I removed all species height data only recorded in one year so that only species measured in both years were used for analysis.

To compare change in woody species height between 2013 and 2014, I conducted linear mixed effects models using Proc Mixed with the restricted maximum likelihood method (REML) with reservoir, and landform as fixed effects and transect as a random effect (SAS version 9.3, SAS Institute, Inc., Cary, NC; Environmental Systems Research Institute, Inc., Redlands, CA).

Normality of data was tested using Proc Univariate in SAS. Equal variance of data was tested using Levene's test (Levene 1960). Data was transformed as needed using the Boxcox method (Box and Cox 1964). Degrees of freedom were calculated using the Satterthwaite method (Satterthwaite 1946). Pair-wise reservoir and landform comparisons were conducted using Tukey-adjusted least squared means tests.

Structural Equation Modeling

Structural equation modeling (SEM) involves the specification of a multivariate dependence model that can be statistically tested against field data, providing a statistical method to evaluate the dependence of relationships between indicator and latent variables through analysis of covariances. Essentially, SEM tests an expected covariance matrix against an actual covariance matrix using multiple indicators which has been shown to provide both enhanced accuracy and precision (Grace and Pugesek 1997). A comprehensive structural equation model synopsis including terminology can be found in Pugesek and Tomer (1996).

The Latent variables depicted in structural equation models are enclosed by ellipses, indicator variables are enclosed in boxes. Path coefficients between variables are standardized partial regression coefficients. Arrow widths are proportional to the standardized path coefficient. Arrows between latent variables and indicators represent the degree to which indicators correlate with latent variables. Arrows between latent variables show the direction, sign, and partial regression coefficients. Dotted lines represent fixed factors and in this case scaling by fixed factor loadings. Circular arrows leading back to the variables represent residual error from unexplained causes (Epskamp 2015).

The relationship between reservoir species richness, cover, and woody species height and the measured environmental variables described above was determined through structural equation models. A Kendall rank correlation coefficient (τ) matrix was constructed in RStudio (RStudio R version 3.1.0 (2014-04-10) using the Harrell Miscellaneous package (Harrell 2014) to look for colinearity among environmental covariates in 118 plots. Environmental variables with $\tau < 0.2$ when compared to all other environmental covariates were selected as the SEM observed (or indicator) variables.

The observed variables were correlated to five latent variables thought to have the greatest impact on vegetation recovery rates, including sediment fertility, ground cover, hydrology, reservoir, and landform/dispersal. Indicator variables correlated to the sediment fertility latent variable are organic matter, Mg, P, and NO_4; these four variables were chosen because they had a $\tau < 0.2$ when correlated with each other. However, the sediment nutrient indicator variables are co-correlated with other sediment variables and act only as a surrogate for those variables in these models. Organic matter was co-correlated with estimated nitrogen release (ENR), cation exchange capacity (CEC), K, Ca, sediment pH, Na, other bases, H, and Al. Magnesium was co-correlated with CEC, Ca, and K. Phosphorus was co-correlated with Na.

Indicator variables correlated to the ground cover latent variable are % bare sediment, % gravel, and % litter; these three variables were chosen because they had a $\tau < 0.2$ when correlated with each other ground cover measures. Indicator variables correlated with hydrology are % silt, % sand, average D50, and sediment depth to refusal; these variables were thought be most affected by river fluvial processes. The indicator variable for the reservoir latent variable was dummy coded as 1 for Mills reservoir and 2 for Aldwell reservoir. Indicator variables correlated to the landform/dispersal latent variable are reservoir landform (coded 1: valley walls, 2: terraces, 3: riparian landforms) and distance in meters from the closest forest edge (Fig. 2.2).

Structural equation models were constructed in RStudio (RStudio R version 3.1.0 (2014-04-10) using the lavaan (Rosseel 2012) and semPlot (Epskamp 2014) packages.

Alternative models were built by adding or taking away indicator and latent variables from the base model until the most parsimonious model with the lowest AICc was constructed. AICc scores of alternative models were compared to each other and the base model (Fig 2.2) using compareFit found in the semTools package (Pornprasertmanit et al. 2014). Standardized root mean square residuals (srmr) were used to determine the fit of the model; srmr is an absolute measure of fit and a srmr score < 0.08 is considered a good fit (Hu and Bentler 1999).

Indicator species Analysis

To determine which plant species were important for distinguishing different vegetation communities among reservoirs and landforms, I conducted randomized indicator species analysis with 1000 runs in PC-ORD using reservoirs and landforms as separate grouping variables (Dufrene and Legendre 1997; PCORD version 5.33 MJM Software Design, Gleneden Beach, OR). Prior to indicator species analysis, plant species that occurred in two plots or fewer (Appendix I) and all plots sampled only one year (Appendix II) were removed from analysis. The input data for the ordination showing change in vegetation composition between years (Fig. 3.12) comprised 59 plots sampled both years by 137 species. Generally only plant species with an indicator value (IV) greater than 20 and a significant Monte Carlo p-value are reported, with the exception being Mills terraces which had no plant species with an IV greater than 20.

Community Composition Analysis

To analyze change in plant community distributions among reservoirs and landforms between 2013 and 2014, I used nonmetric multidimensional scaling (NMS) ordination. Plant species that occurred in two plots or fewer (Appendix I) and all plots sampled only one year (Appendix II) were removed from analysis. The primary matrix comprised species cover values for 137 species which occurred differently in each of the 59 plots sampled both years. To visualize change in vegetation communities within the two reservoirs and among the three landforms, successional vectors were added to the ordination. For change vector analysis I calculated the difference in Sorenson dissimilarity between 2014 and 2013 for each plot; then I grouped the differences between plots by reservoir and landform and averaged the results accordingly (Fig 3.13).

I also used NMS ordination to compare plant community distributions within the two reservoirs and among the three landforms in 2014. The primary matrix for this ordination comprised species cover values for 188 species that occurred in 60 plots: 149 species and 28 plots in Aldwell; 122 species and 32 plots in Mills.

Plots were ordinated according to similarity in species composition measured as Sorensen distance. The NMS starting coordinates had a supplied seed of 14. A fake species cover value of 0.0001 was added to all plots to include plots without plant covers in the ordination. Ordinations were run in PCOrd (PCORD version 5.33 MJM Software Design, Gleneden Beach, OR). Each ordination was run with up to four dimensions, with the final dimensionality of the solution selected when additional dimensions provided less than 5% reduction in stress. The best solution was chosen out of 50 runs of real data with 250 iterations and a stability criterion set at 1 x 10^{-5} and 60 runs of randomized data for a Monte Carlo test of significance. Varimax rotation was selected to maximize loading of species cover onto ordination axes (Mather 1976, Kruskal 1964, McCune and Grace 2002, McCune and Mefford 2006, PCORD version 5.33 MJM Software Design, Gleneden Beach, OR). Environmental covariates, including 43 sediment characteristics and 2 cover measures, were overlaid on the ordination based on Kendall rank correlation coefficient (τ) between the predictor matrix data and ordination axes. Red vectors represent the environmental variables correlated with either axis with an $r^2 > 0.20$. The significance of the relationship to each axis was indicated by the direction and length of the lines representing each individual environmental covariate species cover.

RESULTS

Environmental

Aldwell reservoir contained greater amounts of sediment nutrients (Table 3.1, deeper sediment depth to refusal (86 cm vs 31 cm, $p \leq 0.0001$; Table 3.1), and had greater litter ground cover (46 % vs 6 %, $p \leq 0.0001$; Table 3.2) than Mills reservoir. Mills reservoir had greater gravel (42 % vs 9%, $p \leq 0.0001$; Table 3.2) ground covering and coarser sediments (D50= 8.96 mm vs. 2017 mm $p \leq 0.0001$; Table 3.3, Table 3.4) than Aldwell reservoir. Riparian and terrace landforms had the coarsest sediments, while valley walls had the finest sediments (Fig. 3.1, Table 3.5).

Vegetation Overview

In 2013, 171 vascular plant species were sampled in Aldwell reservoir, of which 53 (31%) were exotic, while 100 vascular plant species were sampled in Mills reservoir, of which 25 (25%) were exotic. The following year, 20 fewer vascular plant species were sampled in Aldwell reservoir, while 23 more vascular plant species were sampled in Mills reservoir (the proportion exotic did not change). In total, 147 vascular plant species were sampled in both reservoirs during the two years of my study, of which 47 (31%) were exotic (Appendix I).

Native Species

Structural equation models found native species richness was highest on sites in Mills reservoir where % organic matter (or co-correlates) and % silt were highest and where % litter, D50, Mg, and P (or co-correlates) were least ($\chi^2{}_{13}$= 25.85, p = 0.018, SRMR = 0.054; Fig. 3.2). Native species cover was found to be highest on valley walls where % litter, % silt, Mg, and P (or co-correlates) were highest and where % organic matter (or co-correlates) and D50 were least ($\chi^2{}_{13}$= 35.21, p = 0.001, SRMR = 0.06; Fig. 3.4).

In 2013, Aldwell reservoir had nearly twice as many native species per plot than Mills reservoir (21 vs. 11 spp.; Fig.3.3; $F_1 = 4.99$, p = 0.05), and four times higher native percent cover (62.5% vs. 14.6%; $F_1 = 7.29$, p = 0.02; Fig. 3.5). By 2014, there was no difference in native species richness or cover between the two reservoirs ($F_1 =$ 1.88, p = 0.2 and $F_1 = 4.35$, p = 0.06 respectively; Table 3.6 and Table 3.7). The highest amounts of species richness and cover were observed along the valley walls while the lowest amounts were observed along riparian landforms (Fig. 3.3, Fig. 3.5). From 2013 to 2014, native species cover increased along Mills terraces and riparian landforms in both reservoirs where the litter layer is the least and sediment is coarsest (Fig. 3.5).

Exotic Species

Structural equation modeling showed that exotic richness was highest on terrace and riparian landforms furthest away from established forest communities where % litter, Mg, and P (or co-correlates) were least and where % organic matter (or co-correlates) was highest ($\chi^2{}_{10}$= 32.40, p = 0, SRMR = 0.071; Fig. 3.6). Exotic cover was highest on valley walls closest to established forest where % gravel, % silt, % organic matter (or co-correlates), and NH_4 are highest and where Mg (or co-correlates) and D50 are least ($\chi^2{}_{19}$= 74.68, p = 0, SRMR = 0.08; Fig. 3.8). While exotic species richness was found to be highest where P (or Na) is highest, exotic species cover was found to be highest where Ammonium nitrate (NH_4) is highest. My field observations of high exotic cover along Aldwell valley walls are consistent with the findings of the SEMs (Table 3.1, Fig. 3.9).

Similar to native species, in 2013, Aldwell reservoir had over four times greater exotic species richness ($\bar{x}$ = 9 spp. vs. $\bar{x}$ = 2 spp.; Fig.3.7; $F_1 = 5.18$, p = 0.05) and nine times greater exotic percent cover (9 % cover vs. 1 % cover; Fig. 3.9; $F_1 = 6.56$, p = 0.04) than Mills reservoir. By 2014, there were no longer significant differences in exotic species richness or cover between the two reservoirs ($F_1 = 3.11$, p = 0.1 and $F_1 = 2.64$, p = 0.1 respectively; Table 3.8 and Table 3.9). The highest amounts of exotic species richness and cover were on the valley walls while the lowest amounts were in riparian landforms (Fig. 3.7, Fig. 3.9).

Woody species Height

Structural equation modelling showed that woody species height was highest on in Aldwell reservoir and along valley walls where organic matter (or co-correlates), % litter, and % silt were highest and where Mg, P (or co-correlates), and D50 were least ($\chi^2{}_{16}$= 36.02, p = 0.003, SRMR = 0.053; Fig. 10). Woody species were twice as tall in Aldwell reservoir compared to Mills in 2013 (119 vs. 60 cm; $F_1 = 5.94$, p = 0.01, Table 3.10). By 2014, woody species height had grown 47% to 175 cm in Aldwell reservoir, but did not change in Mills ($F_1 = 6.05$, p = 0.02 for difference between Aldwell and Mills in 2014). Woody species were tallest on valley walls and terraces in both reservoirs.

Community Composition

Vegetation communities along Aldwell valley walls and terraces changed little from 2013 to 2014 based on NMS ordination (-0.43% $\pm$ 1.8% change and -0.62%$\pm$ 2.38% change, respectively; Fig. 12, Fig. 3.13). Mills reservoir vegetation communities changed also changed very little from 2013 to 2014 (2.19% $\pm$ 1.6% change and 1.19 % $\pm$ 2.4% change, respectively; Fig. 3.12, Fig. 3.13). Four terraces in Mills reservoir showed the most change. These terrace plots had no vegetation present in 2013, but richness increased ranging from 7 to 17 species present in 2014, including the most common species among the 4 plots: *Deschampsia elongata, Epilobium brachycarpum*, and *Pseudotsuga menziesii*. Vegetation communities along riparian zones in both reservoirs showed the most change between 2013 (4.55% $\pm$ 15.44% change (Aldwell) and 5.17% $\pm$ 5.44% change (Mills); Fig. 3.12, Fig. 3.13). The combined years NMS ordination used to determine species composition change through time recommended a 2-dimensional final solution with a final stress of 16.89, and a final instability of 0.00111 (Monte Carlo t-test, p=0.016). Axis 2 explained 73% of the variance in the distance matrix (r^2 = 0.73) (Fig. 3.12, Appendix VI).

Plant communities overlapped between Aldwell valley walls and terrace plots (Fig. 3.14). Reservoirs are separated along axis 1 of the ordination diagram (Fig. 3.14), while landforms were differentiated along axis 2. Environmental covariates associated with Aldwell valley wall and terrace communities were cation exchange capacity, K. bases, H, estimated nitrogen release, organic matter, native species cover, % litter, % silt, and % clay (Fig. 3.14). Plant communities overlapped little among the landforms in Mills Reservoir (Fig. 3.14). Mills terraces were associated with sediment pH, Mills riparian landforms were associated with % sand (Fig. 3.14). The NMS ordination used to compare species composition between Aldwell and Mills reservoirs in 2014 only recommended a 2-dimensional final solution with a final stress of 18.29, and a final instability of 0.00928 (Monte Carlo t-test, p=0.016). Axis 2 explained 73% of the variance in the distance matrix (r^2 = 0.78) (Fig. 3.14, Appendix VIII).

The top three indicator species for Aldwell valley walls were *Acer macrophyllum, Alnus rubra*, and *Ranunculus repens;* while the top three indicators for Mills valley walls were *Deschampsia elongata, Epilobium ciliatum, Epilobium brachycarpum.* The top three indicator species for Aldwell terraces were *Hypochaeris radicata, Leucanthemum vulgare*, and *Plantago lanceolata;* while for Mills terraces they were *Lupinus rivularis* (which may have got its introduction into Mills reservoir through seeding activities of the NPS) and *Rumex acetosa*. Finally, the top three indicator species for Aldwell riparian landforms were *Juncus bufonius, Mimulus lewisii,* and *Juncus bufonius;* while for Mills riparian landforms they were *Lupinus rivularis*, *Claytonia parviflora,* and *Poa annua.*

DISCUSSION

Overall, native species richness was two times higher than exotic species richness and native species cover was ten times higher than exotic species cover. While exotic species were clearly present, they were not dominant (opposite to Orr and Stanley 2006, Orr and Koenig 2006). As predicted Aldwell reservoir contained greater native and exotic species richness, cover, and woody species height than Mills reservoir, which is likely due to the deeper, finer textured sediments which contain higher nutrients. Landforms also differed substantially in species composition, richness, and cover, and will likely form different vegetation communities among the two reservoirs. Similar to trends observed in vegetation recovery following the eruption of Mt. St. Helens where vegetation recovery is expected to follow temporal trends in response to stochastic processes, contingencies, and landscape factors (del Moral et al. 2010); I expect the formation of multiple vegetation communities among the two reservoirs dependent on site specific conditions associated with landform.

As predicted valley walls became similar landforms in terms of native and exotic species richness and cover by 2014, however, woody species heights and compositions remained different. Vegetation composition along valley walls also changed the least from 2013 to 2014 in contrast to the alluvial terrace and riparian landforms, however, some native and exotic species declined along Aldwell valley walls and terraces. The observed decline in species richness along Aldwell valley walls and terraces could expose sediment for colonization and reduce competition for sediment resources and light, all of which could potentially increase exotic species cover.

A notable example of native species decline along valley walls and terraces was *Equisetum arvense and E. sylvaticum,* which carpeted Aldwell reservoir in 2013, but had mostly dried out by 2014. A similar decline in *Equisetum spp*. from 40 to 10% cover was observed two years following the drawdown of Myrkdalen Lake in Norway and was attributed to declining water levels (Odland and del Moral 2002). The loss of *Equisetum sp.* could represent a shift in dominance as species composition increases in similarity to surrounding upland compositions or as conditions change from mesic to xeric; similar to trends in species turnover observed during the drawdown of the Horsetooth Reservoir, Colorado (Auble et al. 2007). Other possible reasons for native species decline along Aldwell valley walls and terraces could be the litter layers created by *Salix lucida*, *Salix sitchensis*, *Alnus rubra*, and *Populus balsamifera ssp. trichocarpa* preventing colonization or successful germination of native species. The litterfall from the willows (and possibly other deciduous trees) could also indirectly shape vegetation successional pathways and plant community characteristics by mediating nutrient and carbon cycling (O'Keefe and Naiman 2006).

Although species richness declined, native and exotic species cover both increased along Aldwell valley walls and terraces where sediment was finest. Aldwell valley walls and terraces were correlated with K and organic matter matching results by Werner (2014) that greater vegetation cover was related to K and organic matter. The fact that the structural equation models showed that species cover and woody species height would be highest where % silt was highest and average coarse particle size was least, combined with the initial revegetation patterns discussed in this paper and the results of another study, suggest that overtime Aldwell valley walls and terraces may become a more forested community because they contained finer, deeper rooting soils, lower sediment pH (Werner 2014), and greater percent organic matter and litter. These two landforms do not appear to need active management to recover aside from exotic species prevention measures. Continued monitoring and management by the NPS should ensure exotic species abundance does not increase, otherwise the reservoirs could become a gateway of species invasion into a relatively protected landscape.

Initial recolonization and growth in Mills reservoir was slow and landforms (with the exception of valley walls) either contained sparse vegetation or no vegetation in 2013. By 2014, grass, forb, and woody species began to colonize the bare ground increasing species richness and cover so by 2014 the only significant difference between Aldwell and Mills reservoir was woody species height. A great example of woody species colonization in Mills reservoir was *Populus balsamifera ssp. trichocarpa* which dramatically increased along Mills' western terraces by 2014. Greater colonization of woody species along the western terraces matches patterns observed by the NPS in 2013 that *Alnus rubra* and *Populus balsamifera ssp. trichocarpa* were higher along the northwestern valley walls; suggesting wind patterns affecting anemochory may be affecting woody species colonization to be higher relative to the east side even though there are mature forests on both sides (J. Chenoweth, National Park Service, unpublished report).

Even though woody species colonization increased along Mills valley walls and terraces, woody species height increased the least in Mills reservoir. The low growth rates in Mills could suggest that plants are limited by environmental factors such as infertile or dry sediments (Parsons 1968), and will generally recolonize more slowly than in Aldwell. Vegetation communities along Mills valley walls and terraces were also correlated with sediment pH which was found to be negatively correlated with tree cover (Werner 2014); suggesting that the differences in sediment pH between reservoirs may be an important reason why woody species heights in Aldwell reservoir were greater than woody species heights in Mills reservoir.

Vegetation communities along terraces were the least similar landforms between reservoirs suggesting that terraces may create novel systems unique to the environmental conditions present in either reservoir. Native species richness and cover both remained low along terraces in Mills reservoir. The likely difficult environmental conditions present along Mills terraces may mean that vegetation recovery will require assistance by the National Park Service. Continued planting and seeding will should increase species richness, but as long as the sites remain dry the planted species may not survive overtime. On dry sites with coarse sediment and little natural vegetation recovery, mulching could improve sediment conditions by increasing soil moisture retention, and reducing runoff, and erosion. Native species richness and cover have been shown to increase 20 months after mulching reservoir sediments in Mills reservoir (Cook et al. 2011).

Mills reservoir contained greater amounts of P and sediment pH (Werner 2014), shallower rooting sediment, and coarser, more gravely sediments (Table 3.1) which may reduce water holding potential making water only available at surface after rainfalls suggesting sediment texture is one environmental factor strongly influencing plant recovery and succession (Henderson et al. 1989, Naiman and Decamps 1997, Brady and Weil 2009). Based on these environmental characteristics and the vegetation recovery patterns discussed, it is likely, at least at first, that Mills valley walls and terraces will resemble grassland communities. Eventually the valley walls may begin to resemble surrounding upland forest communities as the slower growing shade tolerant forest species begin to dominate (Halpern and Spies 1995).

Both native and exotic species increased along riparian zones in both reservoirs. Observations from this study showed that exotic species richness increased the most along riparian zones in each reservoir than on any other landform; suggesting that established vegetation communities along the valley walls and terraces are becoming resistant to invasion and /or that exotic species invasion is strongly influenced by hydrochory or fluvial processes which remove litter and established vegetation leaving exposed ground for colonization. The increase in exotic species also occurred despite active management by the NPS to control exotics. If exotic species colonization is influenced by hydrochory the exposed ground and modified conditions created through dam removal could enable exotic species to invade at more rapid rates than native species extening their ranges along riparian corridors (Lonsdale 1993, Hood and Naiman 2000, Merritt and Wohl 2002).

However, riparian landforms in both reservoirs will likely remain unstable for decades while the river forms an equilibrium channel with new floodplains, terraces, active channel shelves, and depositional bars (Pizzuto 2002). Consequently, vegetation communities along riparian landforms showed the most change and even appear to be becoming more similar between reservoirs in terms of species richness, cover, composition, and woody species height. I expect that overtime reservoir riparian communities will remain similar since they are currently following similar trends in revegetation and are influenced by the fluvial processes of the same river. I predict eventually the vegetation communities along riparian landforms in both reservoirs will come to resemble those of the upper reach on the Elwah River (Cubley 2015).

Conclusion

The public's perception of the success or failure of dam removal restoration projects or other restoration projects following major disturbances can be measured by vegetation recolonization and growth rates (Pywell et al. 2003). While exotic species were clearly present, they were not dominant with only half as many species and a tenth the cover as natives. This may be in part due to active control, but may also be related to conditions in the reservoirs. The greater number of exotic species in Aldwell than Mills is likely due to Aldwell containing finer, more fertile sediments (Lenhart 2000, Werner 2014), but could also be influenced by the greater amount of anthropogenic land use around Aldwell reservoir.

Exotic species colonization was still lower in Aldwell and Mills reservoirs than in other drained reservoirs and the lower colonization rates by exotic species could be due to land use practices around the reservoirs; for instance Mills reservoir is completely enclosed within the Olympic National Park, and Aldwell reservoir is actively being managed to reduce exotic species colonization. Dam removal sites with high exotic species colonization tend to be surrounded by agricultural land, mowed parkland, or other miscellaneous anthropogenic uses (Lenhart 2000, Orr and Koenig 2006, Orr and Stanley 2006).

Surrounding land use is one general thing to consider regarding vegetation recovery post-dam removal. Other general considerations should include size of dam removed (Hart et al. 2002), time of dam removal (Lenhart 2000), river size (O'Connor et al. 2015), and potential for dispersal of exotic plant species (Woodward et al. 2011). More specific considerations based on results from this and other studies include sediment texture which may be one of the strongest predictors of how fertile a site is and therefore how likely natural recolonization is to occur (Henderson et al. 1989, Naiman and Decamps 1997, Brady and Weil 2009, Cavaliere and Homann 2012, J. Chenoweth, National Park Service, unpublished report). Also % organic matter, % litter, % gravel, and distance from established forest edges were all shown in this study to strongly influence natural vegetation recovery. I suggest including all of these factors into predicting natural vegetation recovery patterns or planning vegetation restoration projects within drained reservoirs.

Plant communities were shown to change frequently during the first four years a following a dam removal in Colorado (Auble et al. 2007), and I expect them to change frequently within the drained reservoirs along the Elwha River, especially riparian landforms. However, knowing how environmental conditions within reservoirs affects vegetation recolonization can help land managers know where to actively manage (i.e. sites expected to have high exotic species or site expected to have no to sparse vegetation recovery) and can guide future dam removal or other restoration projects by indicating where to spend the most time and money on restoration efforts.

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Table 2.1. Landform Classifications by elevation above river channel, distance from river channel and forest edge, and average coarse partical size. ± Standard error

Reservoir	Landform	Average Elevation above Channel (m)	Distance (m) River Channel	Distance (m) Established Forest	Average Coarse Sediment Size (mm)
Aldwell	Valley Wall	12.40 ± 2.02	114.03 ± 14.80	21.75 ± 3.51	1.11 ± 0.08
Aldwell	Terrace	6.28 ± 0.71	82.03 ± 15.59	131.20 ± 12.89	2.82 ± 0.63
Aldwell	Riparian	1.22 ± 0.19	51.46 ± 18.48	102.47 ± 10.06	2.33 ± 1.15
Mills	Valley Wall	15.99 ± 3.18	242.82 ± 37.71	44.80 ± 8.32	2.63 ± 0.75
Mills	Terrace	7.31 ± 0.85	131.18 ± 18.39	150.07 ± 14.86	10.83 ± 2.36
Mills	Riparian	1.89 ± 0.36	44.20 ± 8.29	287.59 ± 30.33	12.69 ± 3.65

Table 2.2. Number of vegetation sampling plots by landform

Reservoir	Landform	2013	2014
Aldwell	Valley Wall	n = 9	n = 9
Aldwell	Terrace	n = 17	n = 16
Aldwell	Riparian	n = 4	n = 3
Mills	Valley Wall	n = 12	n = 10
Mills	Terrace	n = 18	n = 14
Mills	Riparian	n = 7	n = 8

Table 3.1. Comparisons of average (±1 SD) reservoir environmental covariates measured in 2014

Environmental Covariates	Aldwell	Mills
Total Exchange Capacity (ME/100 g) (CEC)	8.75 ±2.073	4.43 ±0.96
pH (H2O 1:1)	5.54 ±0.55	5.92 ±0.69
Organic Matter (humus) %	1.81 ±1.01	0.57 ±0.42
Estimated Nitrogen Release lb/A (ENR)	53.14 ±23.39	21.56 ±13.95
SOLUBLE S ppm	31.11 ±22.62	25.56 ±15.65
MEHLICH III lb/A of P	88.43 ±70.96	111.13 ±29.35
MEHLICH III ppm of P	19.29 ±15.47	24.25 ±6.42
Ca Ib/A	1903.14 ±604.53	1080.13 ±382.48
Ca ppm	951.57 ±302.26	540.06 ±191.29
Mg Ib/A	150.93 ±63.70	94.88 ±29.68
Mg ppm	75.46 ±31.85	47.44 ±14.84
K Ib/A	72.71 ±29.29	44.94 ±8.39
K ppm	36.36 ±14.65	22.5 ±4.17
Na Ib/A	41.79 ±6.055	43.69 ±6.467
Na ppm	20.89 ±3.023	21.84 ±3.23
% Ca	55.18 ±14.47	60.80 ±15.80
% Mg	7.18 ±1.80	9.07 ±2.49
% K	1.06 ±0.32	1.33 ±0.21
% Na	1.1 ±0.31	2.24 ±0.59
% Other Bases	6.37 ±1.01	5.78 ±1.12
% H	29.11 ±14.28	20.78 ±16.25
B (ppm)	0.28 ±0.05	1.40 ±5.41
Fe (ppm)	531.96 ±117.54	581.91 ±180.81
Mn(ppm)	36.29 ±14.24	41.19 ±14.78
Cu (ppm)	6.35 ±1.37	5.15 ±1.20
Zn (ppm)	1.77 ±0.40	1.78 ±0.38
Al (ppm)	602.79 ±181.89	404 ±108.78
NO3-N (ppm)	0.61 ±0.55	1.1 ±1.09
NH4-N (ppm)	3.79 ±1.13	3.15 ±0.84
Bray I P (ppm)	3.79 ±1.13	27.44 ±8.75
% Clay	3.73 ±1.13	6.15 ±6.54
% Silt	36.71 ±27.94	17.42 ±26.59
% Sand	58.93 ±32.17	76.43 ±32.93
Sediment Depth to Refusal (cm)	50.97 ±35.98	37.91 ±20.01
% Bryophyte/lichen	1.29 ±3.43	2.281 ±6.02
% Woody debris	7.21 ±10.53	11.36 ±16.83
% Bedrock	0	0.56 ±1.72
% Gravel/cobble	8.54 ±21.72	40.53 ±34.47
% Bare sediment	30.46 ±33.80	37.33 ±29.41
% Litter	53.61 ±38.41	8.28 ±21.25
%water	0	1.75 ±8.87
Average coarse sediment (mm) (D50)	1.68 ±1.83	6.64 ±10.37

Table 3.2 Sampled ground cover by reservoir and year

Reservoir	Year	Ave. Sediment Depth (cm)	%Bryophyte/ lichen	% Wood	%bedrock / boulder	%gravel / cobble	% bare sediment	% litter	% water	% biocrust
Aldwell	**2013**	110.98	0.80	3.82	0.07	8.35	53.02	34.73	0.00	0.00
	2014	61.75	1.29	7.21	0.00	8.54	30.46	55.59	0.00	2.68
	Average	86.36	1.04	5.52	0.03	8.44	41.74	45.16	0.00	1.34
Mills	**2013**	36.63	0.36	10.31	0.64	42.76	41.90	4.58	0.00	0.00
	2014	24.79	2.28	11.36	0.56	40.53	37.33	8.28	1.75	5.78
	Average	30.71	1.32	10.84	0.60	41.65	39.62	6.43	0.88	2.89

Table 3.3. Coarse particle size (D50) by reservoir, year, and landform

years	2013	2014	Average			
reservoirs						
Aldwell	2.67 mm	1.67 mm	2.17 mm			
Mills	11.27 mm	6.640 mm	8.95 mm			
landforms	Aldwell riparian	Aldwell terrace	Aldwell Valley wall	Mills riparian	Mills terrace	Mills valley wall
years						
2013	3 mm	3.43 mm	1.1 mm	15.61 mm	13.84 mm	4.88 mm
2014	1 mm	2.13 mm	1.1 mm	11.36 mm	7.82 mm	1.2 mm
Average	2 mm	2.78 mm	1.1 mm	13.49 mm	10.84 mm	3.04 mm

Table 3.4. Two-way factorial ANOVA results comparing coarse particle size (D50) between reservoir and year

ANOVA results (D50 ~ reservoirs * years)					
	Df	SS	MS	*F*	*P*
Reservoirs	1	1513	1513.3	20.784	1.22×10^{-05}
Years	1	279	278.9	3.831	0.0526
Reservoirs:Years	1	104	103.7	1.425	0.2349
Residuals	123	8955	72.8		

Tukey multiple comparisons of means
95% family-wise confidence level

reservoirs	
	P adjusted
Mills-Aldwell	1.22×10^{-05}
years	
	P adjusted
2014-2013	0.052627
reservoirs:years	
	P adjusted
Mills:2013-Aldwell:2013	0.000428
Aldwell:2014-Aldwell:2013	0.970441
Mills:2014-Aldwell:2013	0.265223
Aldwell:2014-Mills:2013	9.49×10^{-05}
Mills:2014-Mills:2013	0.116043
Mills:2014-Aldwell:2014	0.116454

Table 3.5. Two-way factorial ANOVA results comparing coarse particle size (D50) between landform and year

ANOVA results (D50 ~ landforms * years)					
	Df	SS	MS	*F*	*P*
years	1	304	304	4.551	0.035
landforms	5	2721	544.2	8.148	1.30×10^{-06}
years:landforms	5	146	29.1	0.436	0.823
Residuals	115	7681	66.8		

Tukey multiple comparisons of means
95% family-wise confidence level

years		
	P adjusted	
2014-2013	0.0350227	
landforms		
Aldwell terrace	Aldwell riparian	0.99988
Aldwell valley wall	Aldwell riparian	0.999923
Aldwell valley wall	Aldwell terrace	0.983363
Mills riparian	Aldwell riparian	0.089828
Mills terrace	Aldwell terrace	0.001159
Mills valley wall	Aldwell valley wall	0.974532
Mills terrace	Mills riparian	0.932202
Mills valley wall	Mills riparian	0.003187
Mills valley wall	Mills terrace	0.008152

Table 3.6. Native species richness linear mixed effects model results

Native Species Richness 2013 Tests of Fixed Effects

Effect	Num DF	Den DF	F	P
Reservoir	1	8.26	4.99	0.055
Landform	2	41	2.26	0.12
Reservoir*Landform	2	41	1.24	0.30

Native Species Richness 2014 Tests of Fixed Effects

Effect	Num DF	Den DF	F	P
Reservoir	1	6.99	1.88	0.21
Landform	2	40.1	5.1	0.01
Reservoir*Landform	2	40.1	0.83	0.44

Native Species Richness 2013 Differences of Least Squares Means

Effect	Reservoir	Landform	Reservoir	Landform	Estimate	SE	DF	t	P	Adj	Adj P
Reservoir	Aldwell		Mills		8.20	3.67	8.26	2.23	0.05	Tukey-Kramer	0.0549
Landform		Riparian		Terrace	7.07	3.71	41.9	1.91	0.06	Tukey-Kramer	0.2
Landform		Riparian		Valley Wall	7.84	3.80	40.5	2.06	0.05	Tukey-Kramer	0.1
Landform		Terrace		Valley Wall	0.77	2.58	41.6	0.3	0.77	Tukey-Kramer	1.0
Reservoir*Landform	Aldwell	Riparian	Mills	Riparian	4.95	7.10	32.7	0.7	0.49	Tukey-Kramer	1.0
Reservoir*Landform	Aldwell	Terrace	Mills	Terrace	6.11	3.93	11.4	1.55	0.15	Tukey-Kramer	0.6
Reservoir*Landform	Aldwell	Valley Wall	Mills	Valley Wall	13.55	4.59	18.2	2.95	0.01	Tukey-Kramer	0.0546

Native Species Richness 2014 Differences of Least Squares Means

Effect	Reservoir	Landform	Reservoir	Landform	Estimate	SE	DF	t	P	Adj	Adj P
Reservoir	Aldwell		Mills		4.46	3.25	6.99	1.37	0.21	Tukey-Kramer	0.21
Landform		Riparian		Terrace	7.18	3.01	41.1	2.38	0.02	Tukey-Kramer	0.055
Landform		Riparian		Valley Wall	9.80	3.07	39	3.19	0.00	Tukey-Kramer	0.01
Landform		Terrace		Valley Wall	2.62	2.09	40.7	1.25	0.22	Tukey-Kramer	0.43
Reservoir*Landform	Aldwell	Riparian	Mills	Riparian	1.66	5.91	31.1	0.28	0.78	Tukey-Kramer	1.00
Reservoir*Landform	Aldwell	Terrace	Mills	Terrace	3.61	3.43	9.06	1.05	0.32	Tukey-Kramer	0.90
Reservoir*Landform	Aldwell	Valley Wall	Mills	Valley Wall	8.12	3.93	14.3	2.07	0.06	Tukey-Kramer	0.32

Table 3.7. Native species cover linear mixed effect model results

Native Species Cover 2013 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F**	**P**
Reservoir	1	9.09	7.29	0.02
Landform	2	40.5	3.33	0.05
Reservoir*Landform	2	40.5	1.68	0.20
Native Species Cover 2014 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F**	**P**
Reservoir	1	9.04	4.35	0.07
Landform	2	41.2	0.81	0.45
Reservoir*Landform	2	41.2	1.54	0.23

Native Species Cover 2013 Differences of Least Squares Means											
Effect	**Reservoir**	**Landform**	**Reservoir**	**Landform**	**Estimate**	**SE**	**DF**	**t**	**P**	**Adj**	**Adj P**
Reservoir	Aldwell		Mills		57.30	21.22	9.09	2.7	0.02	Tukey-Kramer	0.02
Landform		Riparian		Terrace	47.94	19.46	41.3	2.46	0.02	Tukey-Kramer	0.047
Landform		Riparian		Valley Wall	47.22	19.84	39.7	2.38	0.02	Tukey-Kramer	0.056
Landform		Terrace		Valley Wall	-0.72	13.53	41	-0.05	0.96	Tukey-Kramer	1.00
Reservoir*Landform	Aldwell	Riparian	Mills	Riparian	89.06	38.35	33.4	2.32	0.03	Tukey-Kramer	0.21
Reservoir*Landform	Aldwell	Terrace	Mills	Terrace	24.36	22.37	11.5	1.09	0.30	Tukey-Kramer	0.88
Reservoir*Landform	Aldwell	Valley Wall	Mills	Valley Wall	58.48	25.55	17.3	2.29	0.03	Tukey-Kramer	0.22
Native Species Cover 2014 Differences of Least Squares Means											
Effect	**Reservoir**	**Landform**	**Reservoir**	**Landform**	**Estimate**	**SE**	**DF**	**t**	**P**	**Adj**	**Adj P**
Reservoir	Aldwell		Mills		71.91	34.47	9.04	2.09	0.07	Tukey-Kramer	0.07
Landform		Riparian		Terrace	42.03	35.41	42	1.19	0.24	Tukey-Kramer	0.47
Landform		Riparian		Valley Wall	22.06	36.34	40.8	0.61	0.55	Tukey-Kramer	0.82
Landform		Terrace		Valley Wall	-19.97	24.66	41.7	-0.81	0.42	Tukey-Kramer	0.70
Reservoir*Landform	Aldwell	Riparian	Mills	Riparian	49.63	67.49	33.4	0.74	0.47	Tukey-Kramer	0.98
Reservoir*Landform	Aldwell	Terrace	Mills	Terrace	41.06	37.03	12.6	1.11	0.29	Tukey-Kramer	0.87
Reservoir*Landform	Aldwell	Valley Wall	Mills	Valley Wall	125.03	43.40	19.8	2.88	0.01	Tukey-Kramer	0.06

Table 3.8. Exotic species richness linear mixed effect model results

Exotic Species Richness 2013 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F**	**P**
Reservoir	1	8.23	5.2	0.052
Landform	2	38	1.5	0.25
Reservoir*Landform	2	38	0.1	0.92
Exotic Species Richness 2014 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F**	**P**

Reservoir	1	8.47	3.1	0.11
Landform	2	38.8	2.4	0.10
Reservoir*Landform	2	38.8	0.3	0.77

Exotic Species Richness 2013 Differences of Least Squares Means											
Effect	**Reservoir**	**Landform**	**Reservoir**	**Landform**	**Estimate**	**SE**	**DF**	**t**	**P**	**Adj**	**Adj P**
Reservoir	Aldwell		Mills		7.61	3.34	8.23	2.3	0.05	Tukey-Kramer	0.052
Landform		Riparian		Terrace	2.79	2.18	38.3	1.3	0.21	Tukey-Kramer	0.41
Landform		Riparian		Valley Wall	3.74	2.20	37.2	1.7	0.10	Tukey-Kramer	0.22
Landform		Terrace		Valley Wall	0.95	1.51	38.5	0.6	0.53	Tukey-Kramer	0.81
Reservoir*Landform	Aldwell	Riparian	Mills	Riparian	7.33	4.90	26.1	1.5	0.15	Tukey-Kramer	0.67
Reservoir*Landform	Aldwell	Terrace	Mills	Terrace	7.15	3.42	9.08	2.1	0.07	Tukey-Kramer	0.32
Reservoir*Landform	Aldwell	Valley Wall	Mills	Valley Wall	8.36	3.69	11.9	2.3	0.04	Tukey-Kramer	0.23
Exotic Species Richness 2014 Differences of Least Squares Means											
Effect	**Reservoir**	**Landform**	**Reservoir**	**Landform**	**Estimate**	**SE**	**DF**	**t**	**P**	**Adj**	**Adj P**
Reservoir	Aldwell		Mills		4.52	2.56	8.47	1.8	0.11	Tukey-Kramer	0.11
Landform		Riparian		Terrace	0.45	1.88	39.2	0.2	0.81	Tukey-Kramer	0.97
Landform		Riparian		Valley Wall	3.74	1.90	37.9	1.6	0.12	Tukey-Kramer	0.26
Landform		Terrace		Valley Wall	0.95	1.31	39.3	2	0.05	Tukey-Kramer	0.13
Reservoir*Landform	Aldwell	Riparian	Mills	Riparian	7.33	4.01	29.3	0.7	0.46	Tukey-Kramer	0.98
Reservoir*Landform	Aldwell	Terrace	Mills	Terrace	7.15	2.64	9.65	2.2	0.06	Tukey-Kramer	0.28
Reservoir*Landform	Aldwell	Valley Wall	Mills	Valley Wall	8.36	2.89	13.3	1.7	0.11	Tukey-Kramer	0.55

Table 3.9. Exotic species cover linear mixed effect model results

Exotic Species Cover 2013 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F**	**P**
Reservoir	1	6.52	6.56	0.0399
Landform	2	40.4	1.06	0.36
Reservoir*Landform	2	40.4	0.61	0.55
Exotic Species Cover 2014 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F**	**P**
Reservoir	1	8.24	2.64	0.14
Landform	2	41.2	3.39	0.04
Reservoir*Landform	2	41.2	0.29	0.75

	Exotic Species Cover 2013 Differences of Least Squares Means										
Effect	**Reservoir**	**Landform**	**Reservoir**	**Landform**	**Estimate**	**SE**	**DF**	**t**	**P**	**Adj**	**Adj P**
Reservoir	Aldwell		Mills		6.84	2.67	6.52	2.56	0.04	Tukey-Kramer	0.04
Landform		Riparian		Terrace	0.99	3.28	39.5	0.3	0.77	Tukey-Kramer	0.95

Landform		Riparian		Valley Wall	3.94	3.43	42	1.15	0.26	Tukey-Kramer	0.49
Landform		Terrace		Valley Wall	2.95	2.31	41.9	1.28	0.21	Tukey-Kramer	0.42
Reservoir*Landform	Aldwell	Riparian	Mills	Riparian	4.40	5.97	27	0.74	0.47	Tukey-Kramer	0.98
Reservoir*Landform	Aldwell	Terrace	Mills	Terrace	10.13	3.02	12.5	3.36	0.01	Tukey-Kramer	0.02
Reservoir*Landform	Aldwell	Valley Wall	Mills	Valley Wall	5.99	3.70	21.6	1.62	0.12	Tukey-Kramer	0.59
	Exotic Species Cover 2014 Differences of Least Squares Means										
Effect	**Reservoir**	**Landform**	**Reservoir**	**Landform**	**Estimate**	**SE**	**DF**	**t**	**P**	**Adj**	**Adj P**
Reservoir	Aldwell		Mills		13.46	8.28	8.24	1.63	0.14	Tukey-Kramer	0.14
Landform		Riparian		Terrace	17.11	8.66	42	1.97	0.05	Tukey-Kramer	0.13
Landform		Riparian		Valley Wall	23.19	8.90	40.9	2.6	0.01	Tukey-Kramer	0.03
Landform		Terrace		Valley Wall	6.09	6.04	41.8	1.01	0.32	Tukey-Kramer	0.58
Reservoir*Landform	Aldwell	Riparian	Mills	Riparian	14.56	16.43	32.4	0.89	0.38	Tukey-Kramer	0.95
Reservoir*Landform	Aldwell	Terrace	Mills	Terrace	17.51	8.93	11.8	1.96	0.07	Tukey-Kramer	0.38
Reservoir*Landform	Aldwell	Valley Wall	Mills	Valley Wall	8.31	10.51	19.1	0.79	0.44	Tukey-Kramer	0.97

Table 3.10. Woody species height linear mixed effect model results

Woody species Height 2013 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F**	**P**
Reservoir	1	134	5.94	0.02
Landform	2	134	3.52	0.03
Reservoir*Landform	2	134	1.26	0.29
Woody species Height 2014 Tests of Fixed Effects				
Effect	**Num DF**	**Den DF**	**F**	**P**
Reservoir	1	27.3	6.05	0.02
Landform	2	133	4.73	0.01
Reservoir*Landform	2	133	1.59	0.21

Woody Species Height 2013 Differences of Least Squares Means											
Effect	**Reservoir**	**Landform**	**Reservoir**	**Landform**	**Estimate**	**SE**	**DF**	**t**	**P**	**Adj**	**Adj P**
Reservoir	Aldwell		Mills		63.62	26.11	134	2.44	0.02	Tukey-Kramer	0.0
Landform		Riparian		Terrace	-42.85	37.92	134	-1.13	0.26	Tukey-Kramer	0.5
Landform		Riparian		Valley Wall	-77.14	35.88	134	-2.15	0.03	Tukey-Kramer	0.1
Landform		Terrace		Valley Wall	-34.29	18.53	134	-1.85	0.07	Tukey-Kramer	0.2
Reservoir*Landform	Aldwell	Riparian	Mills	Riparian	-11.93	69.02	134	-0.17	0.86	Tukey-Kramer	1.0
Reservoir*Landform	Aldwell	Terrace	Mills	Terrace	103.96	31.43	134	3.31	0.00	Tukey-Kramer	0.0
Reservoir*Landform	Aldwell	Valley Wall	Mills	Valley Wall	98.84	19.62	134	5.04	<.0001	Tukey-Kramer	<.0001
Woody Species Height 2014 Differences of Least Squares Means											
Effect	**Reservoir**	**Landform**	**Reservoir**	**Landform**	**Estimate**	**SE**	**DF**	**t**	**P**	**Adj**	**Adj P**
Reservoir	Aldwell		Mills		97.54	39.66	27.3	2.46	0.02	Tukey-Kramer	0.02
Landform		Riparian		Terrace	-76.70	54.33	134	-1.41	0.16	Tukey-Kramer	0.34

Landform		Riparian		Valley Wall	-131.06	51.24	134	-2.56	0.01	Tukey-Kramer	0.03
Landform		Terrace		Valley Wall	-54.36	26.56	134	-2.05	0.04	Tukey-Kramer	0.11
Reservoir*Landform	Aldwell	Riparian	Mills	Riparian	-21.17	99.69	123	-0.21	0.83	Tukey-Kramer	1.00
Reservoir*Landform	Aldwell	Terrace	Mills	Terrace	172.76	46.74	47	3.7	0.00	Tukey-Kramer	0.00
Reservoir*Landform	Aldwell	Valley Wall	Mills	Valley Wall	141.05	31.17	10.9	4.53	0.00	Tukey-Kramer	0.0002

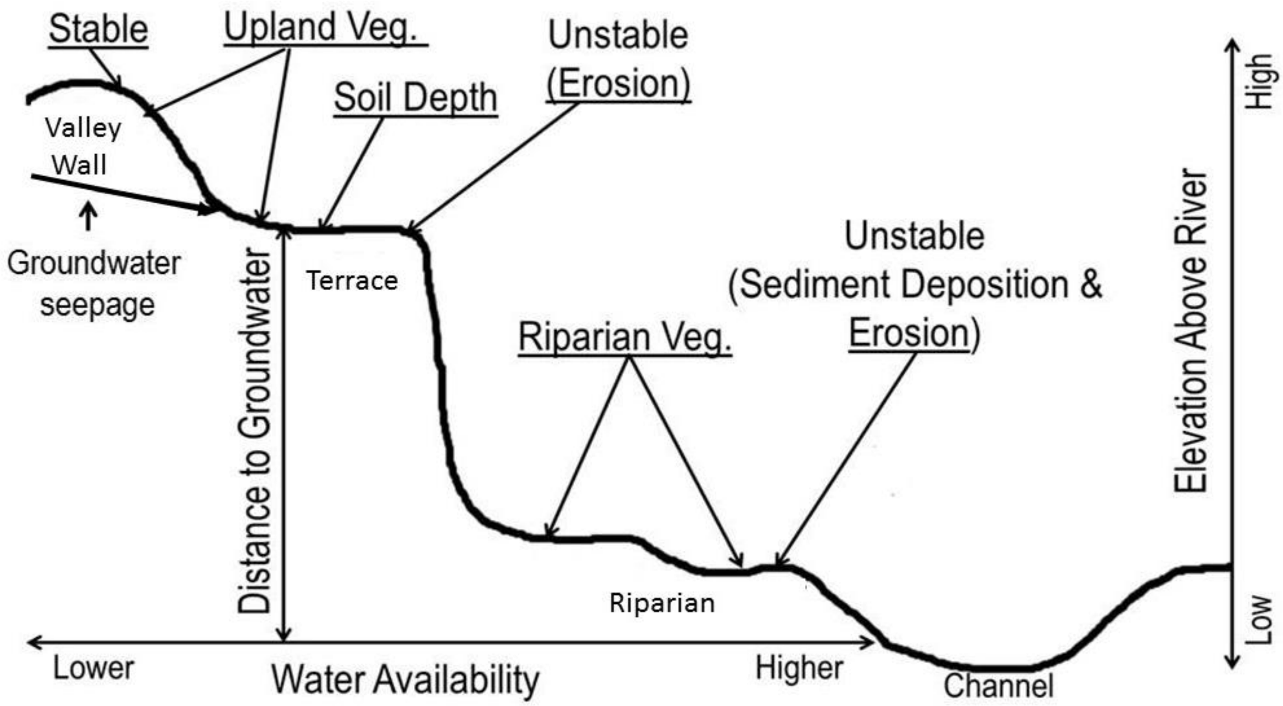

Figure 1.1. Conceptualized cross-sectional diagram of drained reservoir sediments. Upland slopes were previously the lake shore, high terraces were created by the incising river as the reservoirs drained, terraces and bars are formed by fluvial processes.

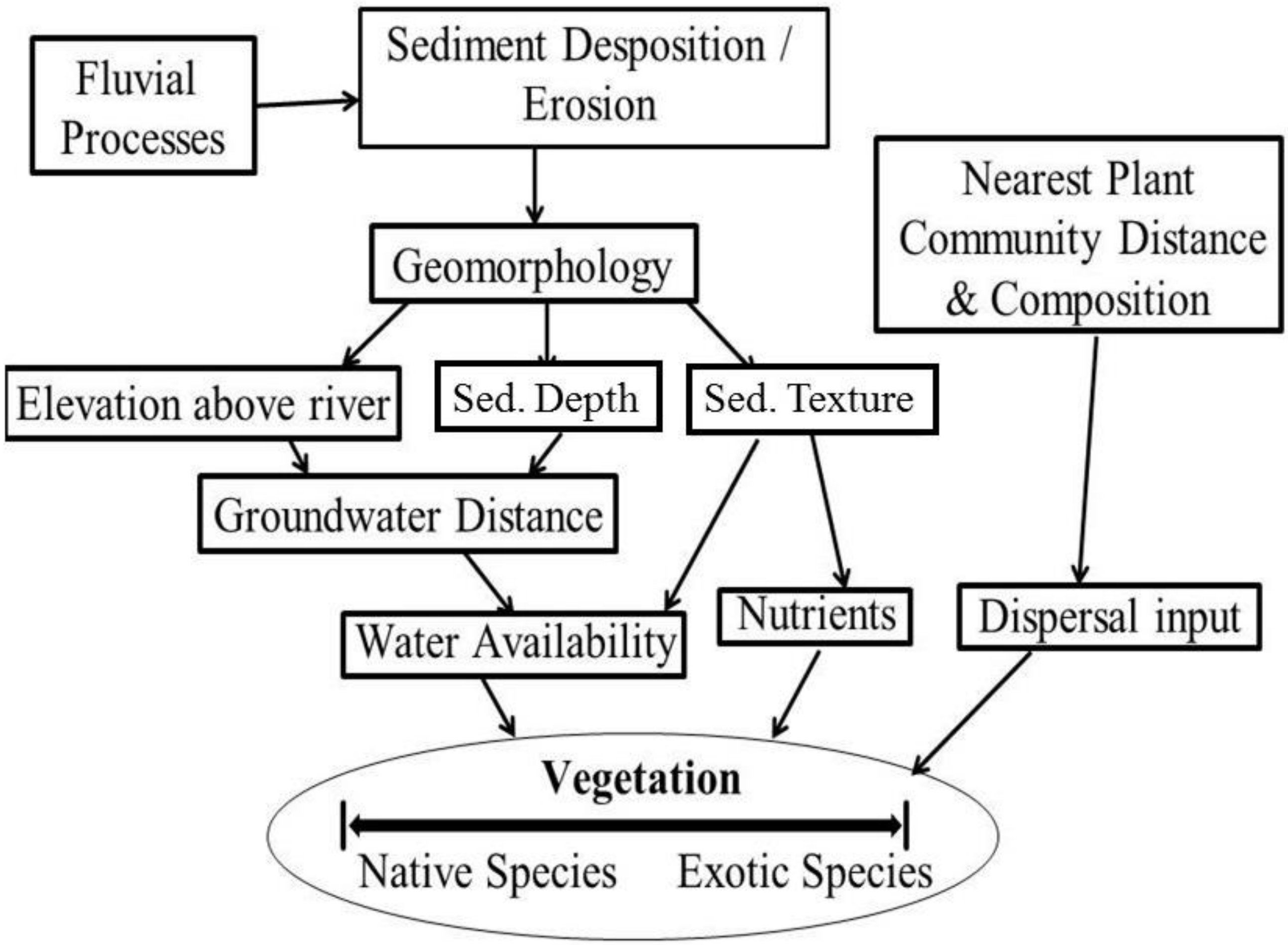

Figure 1.2. A simple conceptual diagram depicting how site-specific attributes may relate to vegetation recovery in the drained reservoirs along the Elwha River, WA. The vegetation communities that could establish may consist of all native or exotic species or a mixture of both leading to the creation of novel ecosystems.

Figure 1.3. The Elwha River is located on the Olympic Peninsula and flows 80 km from the Olympic Mountains into the Strait of Juan de Fuca. The Elwha Dam was located at river kilometer 7.9 and formed Lake Aldwell, the Glines Canyon Dam was located at river kilometer 21.6 and formed Lake Mills. Image by USGS.gov.

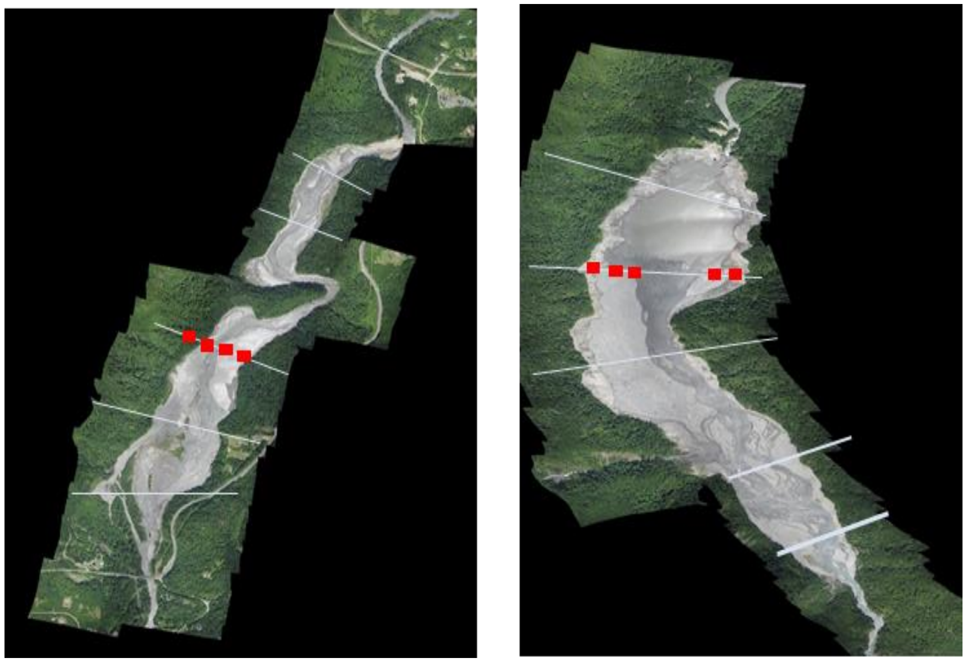

Figure 2.1. Five transects were established perpendicular to the river from reservoir edge to reservoir edge spanning three geomorphic landforms (valley wall, terrace, riparian) in both Aldwell and Mills reservoirs. Plots were located in a stratified random manner on every geomorphic feature crossed by the transect with a range of 4 to 12 100 m^2 plots / transect. A total of 67 100 m^2 plots were sampled in 2013, 8 plots were lost to changing reservoir geomorphology between 2013 and 2014 and one plot was added in 2014 for a total of 60 100 m^2 plots sampled in 2014.

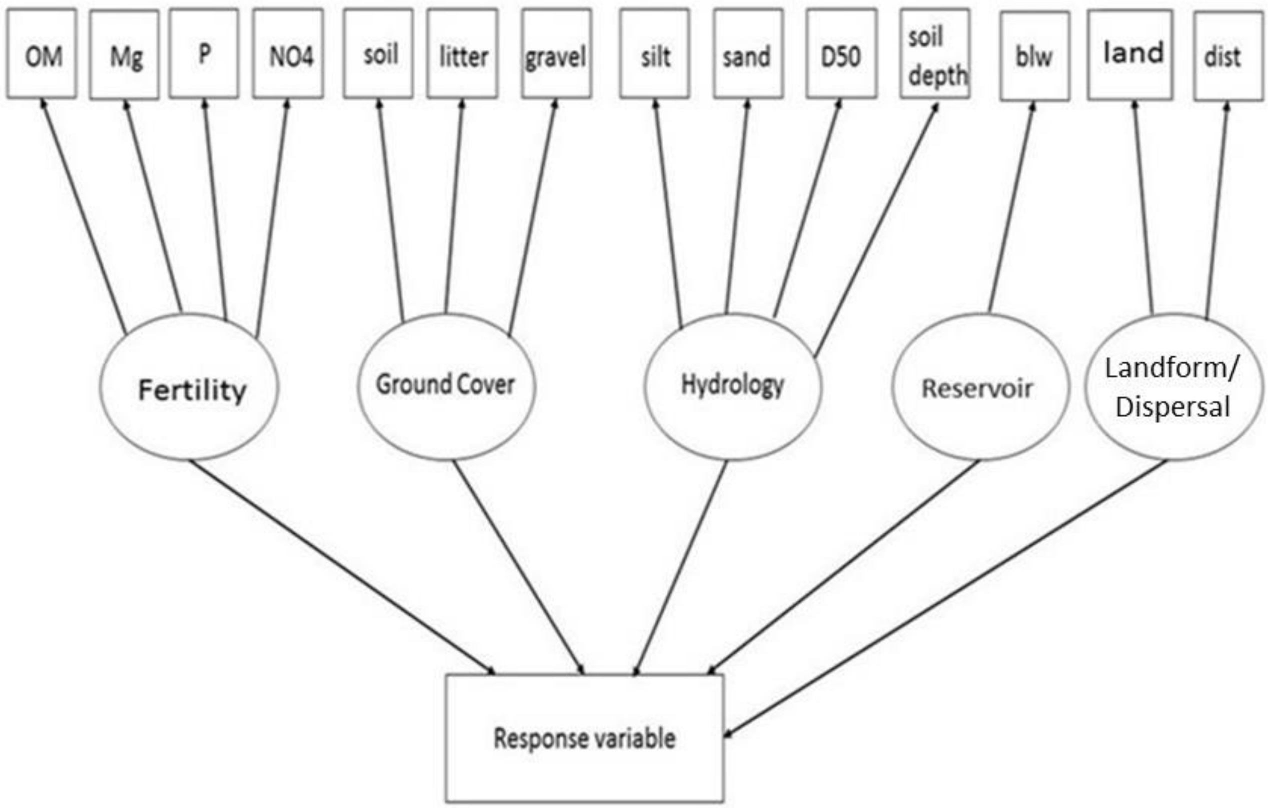

Figure 2.2. Base structural equation model for predicting vegetation the recovery response variables exotic species cover, native species cover, exotic species richness, native species richness, and woody species height. The base model includes 14 indicator variables and 5 latent variables.

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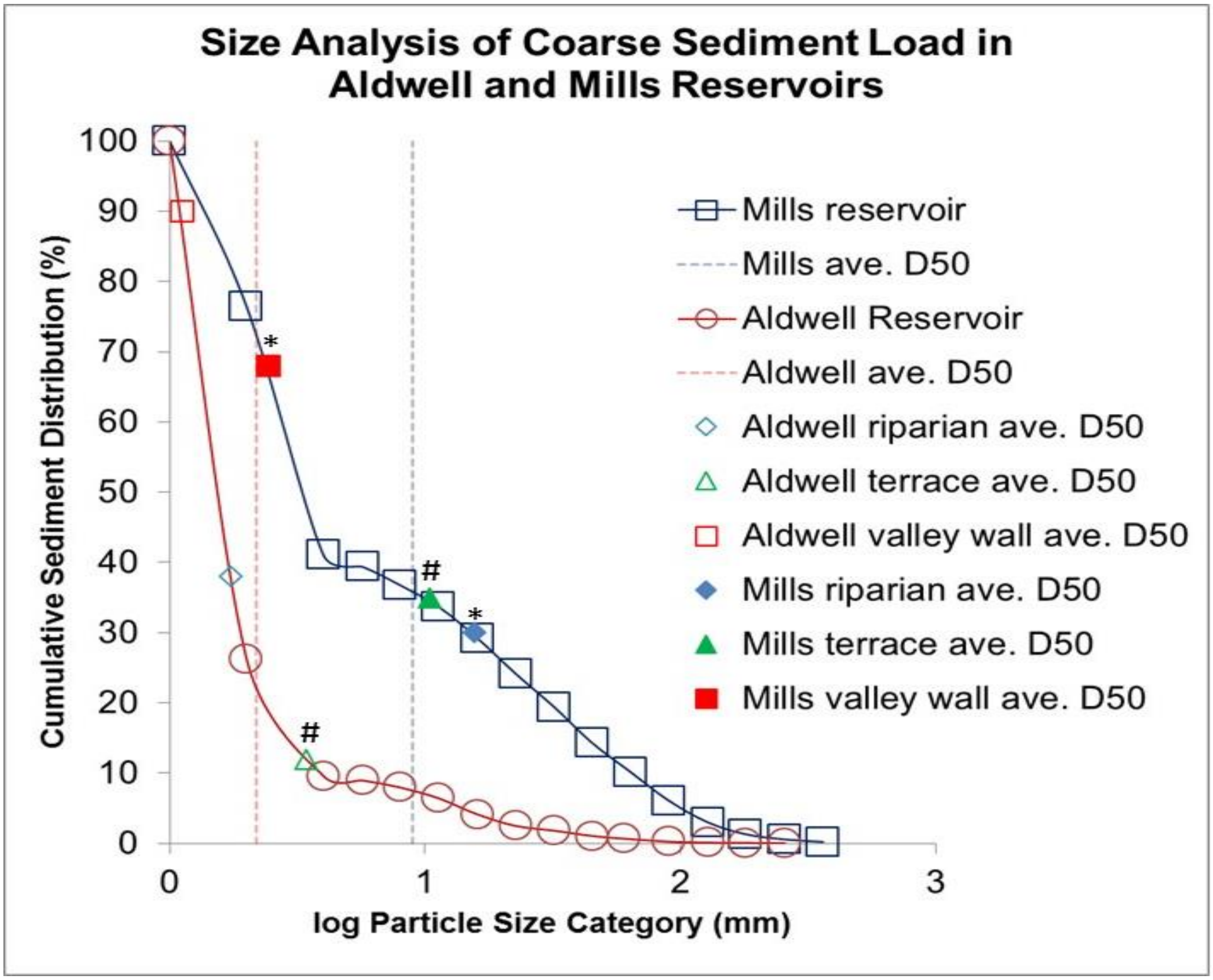

Figure 3.1. Log transformed cumulative frequency curves comparing coarse sediment distribution between Aldwell and Mills reservoirs along the Elwha River, WA. Sediment particle sizes were averaged between 2013 and 2014 for each reservoir. Particle sizes (x-axis) are plotted against the frequency in which they occur within each reservoir (y-axis). Squares, triangles, and rhombuses represent 2013-2014 landform average D50s. Asterisk denotes significance between Mills valley walls and riparian landforms (p=0.001); number signs denote significance between Mills and Aldwell terraces (p=0.003).

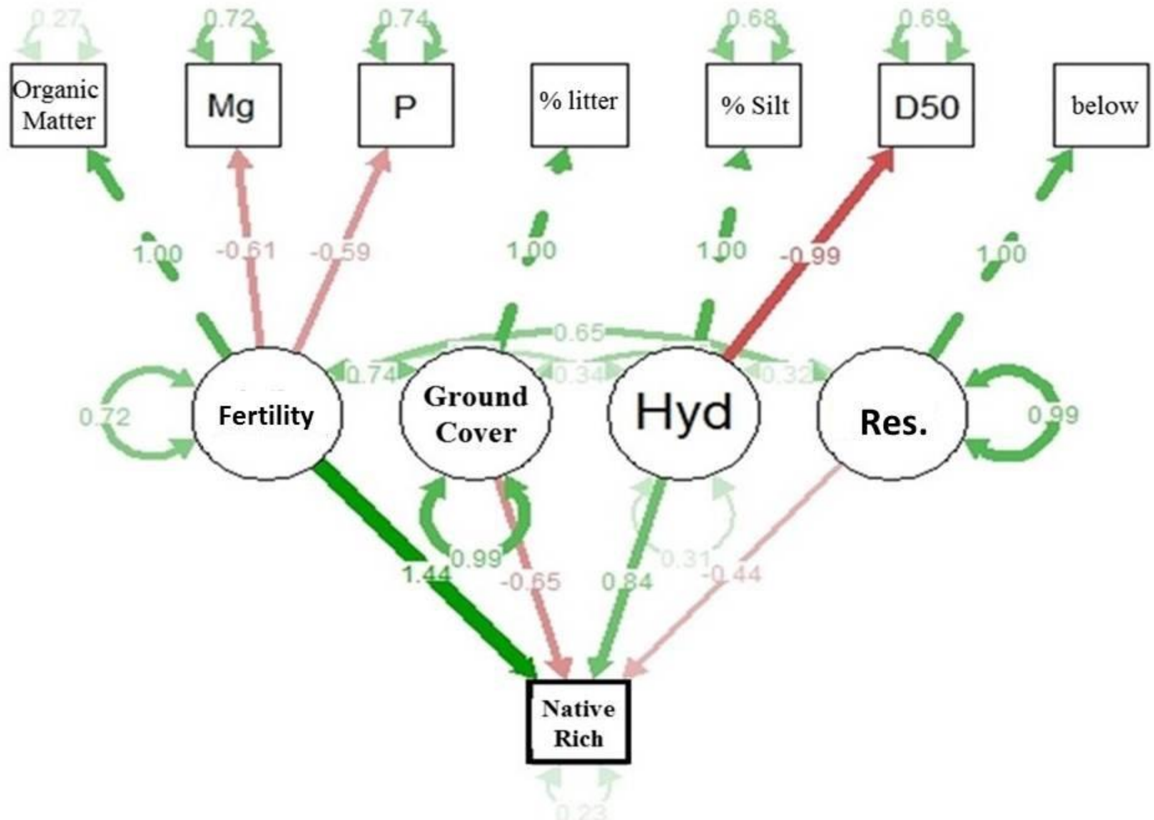

Fig 3.2. Structural equation model showing variables that relate to native richness. Latent variables are enclosed by ellipses, indicator variables are enclosed in boxes. Path coefficients between variables are standardized partial regression coefficients. Arrow widths are proportional to the standardized path coefficient. Arrows between latent variables and indicators represent the degree to which indicators correlate with latent variables. Arrows between latent variables show the direction, sign, and partial regression coefficients. Circular arrows leading back to the variables represent residual error from unexplained causes. Native species richness was best predicted by organic matter, Mg, P, litter, silt, D50, and below Glines Canyon dam (Aldwell reservoir). Goodness-of-fit statistics are: $\chi^2{}_{13} = 25.85$, $p = 0.018$, SRMR = 0.054.

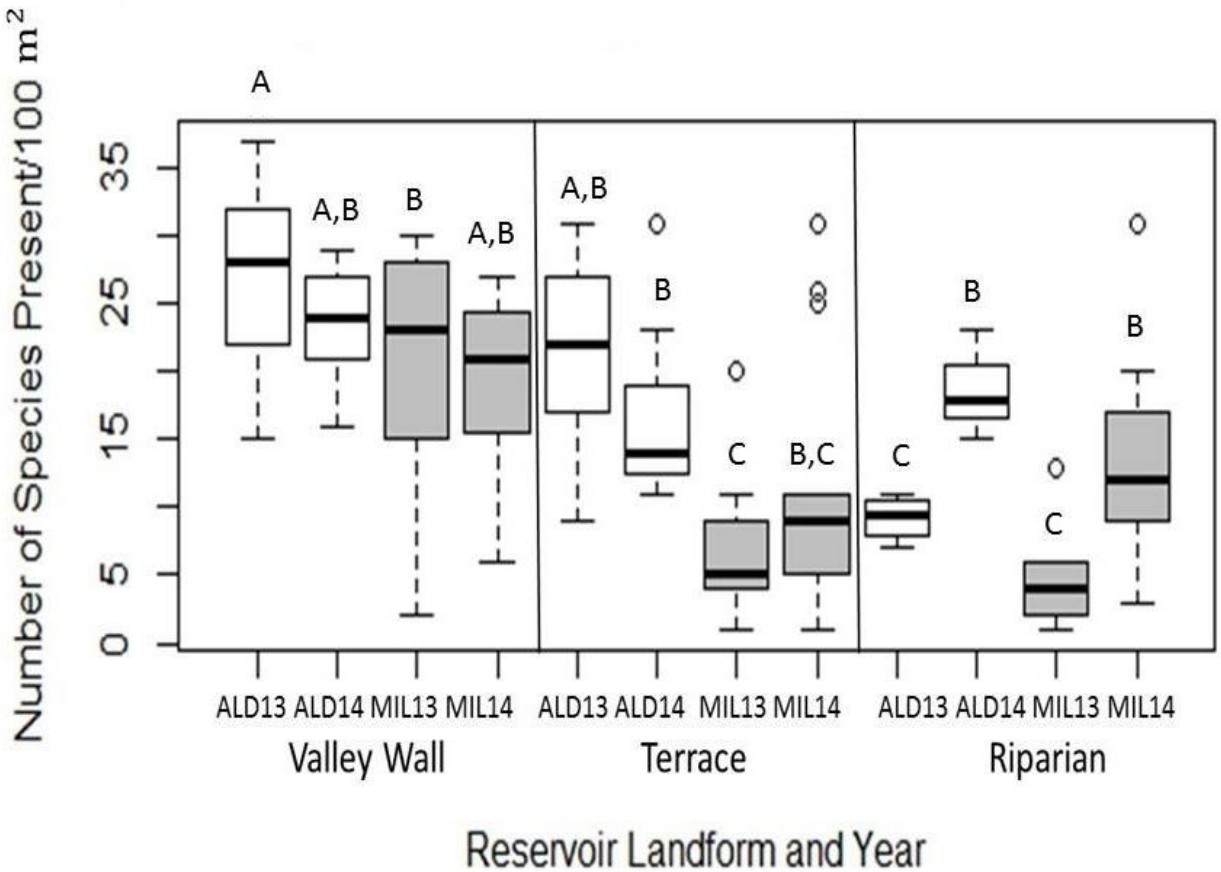

Figure 3.3. Comparison of native vascular species richness (Nspp) between reservoir landforms and years within Aldwell and Mills reservoirs along the Elwha River, WA. Nspp refers to the number of vascular species per 100 m^2 plot. Boxplots represent the total number of native vascular vegetation species sampled in each reservoir. Whiskers represent the variance in the data and the thick black line in each box represents the median number of species. Different letters are significantly different from each other.

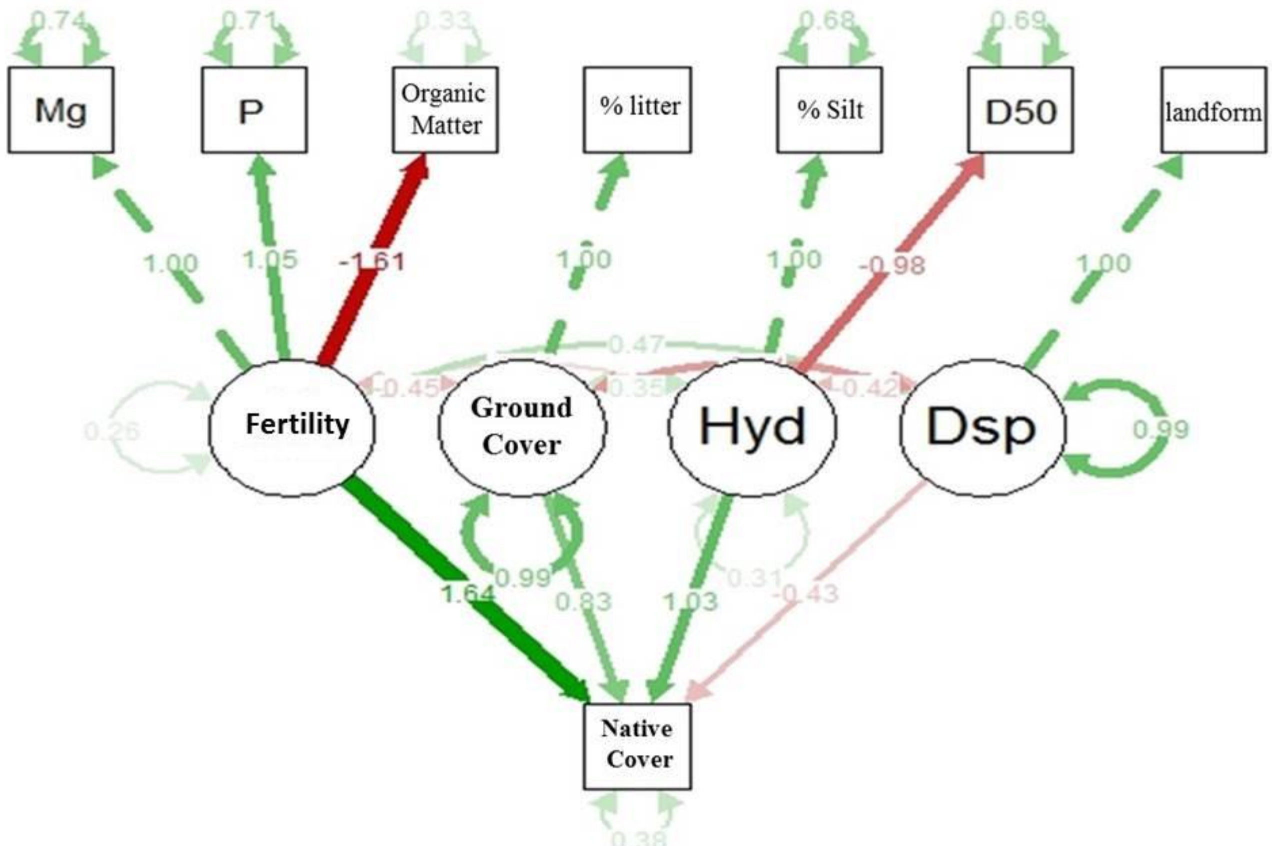

Figure 3.4. Structural equation model showing variables that relate to native species cover. For a detailed explanation of the structural equation model refer to Fig. 3.2. Native species cover is best predicted by organic matter, Mg, P, % litter, % silt, D50, and landform. Goodness-of-fit statistics are: $\chi^2_{13} = 35.21$, $p = 0.001$, SRMR = 0.06.

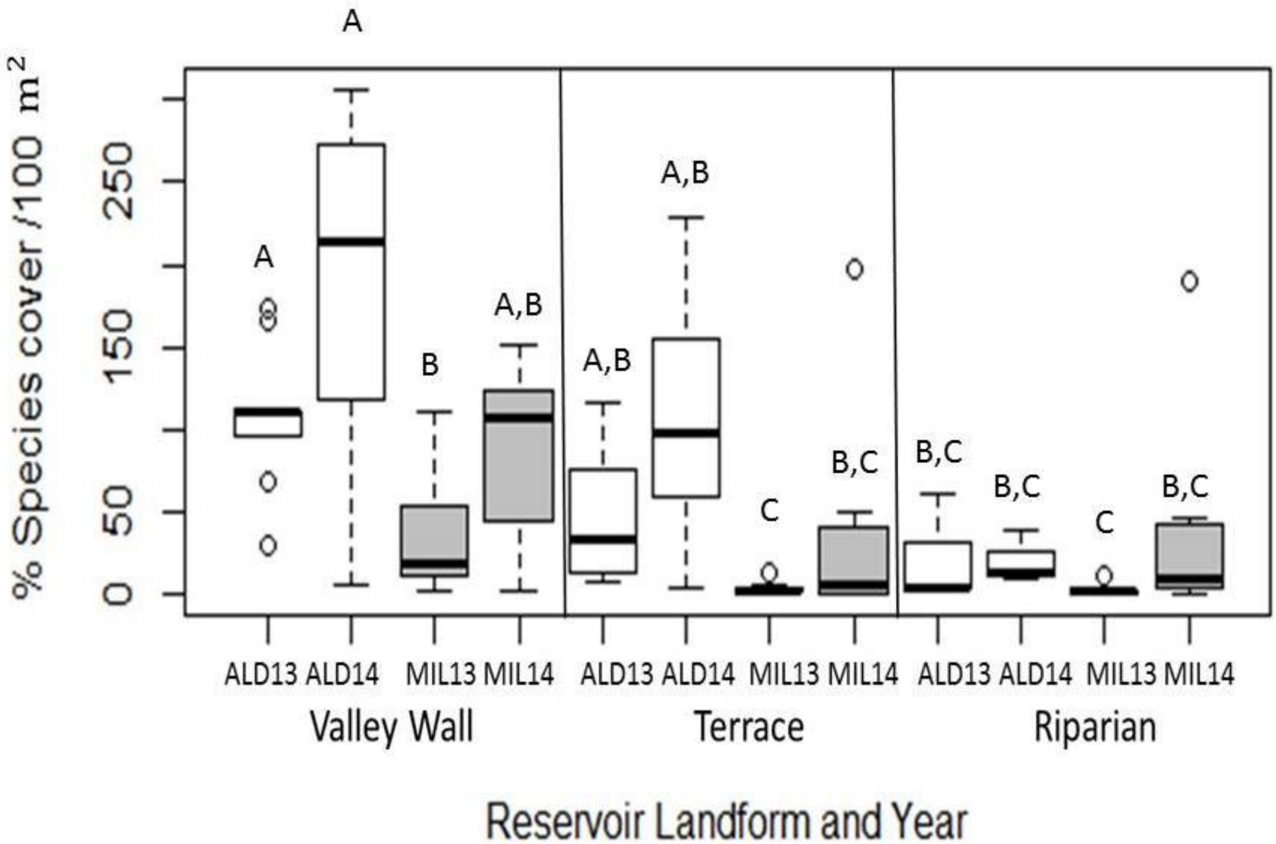

Figure 3.5. Comparison of native vascular species cover (Ncov) between reservoir landforms and years within Aldwell and Mills reservoirs along the Elwha River, WA. Boxplots represent total vascular vegetation cover in each reservoir. Whiskers represent the variance in the data and the thick black line in each box represents the median cover value. Different letters are significantly different from each other.

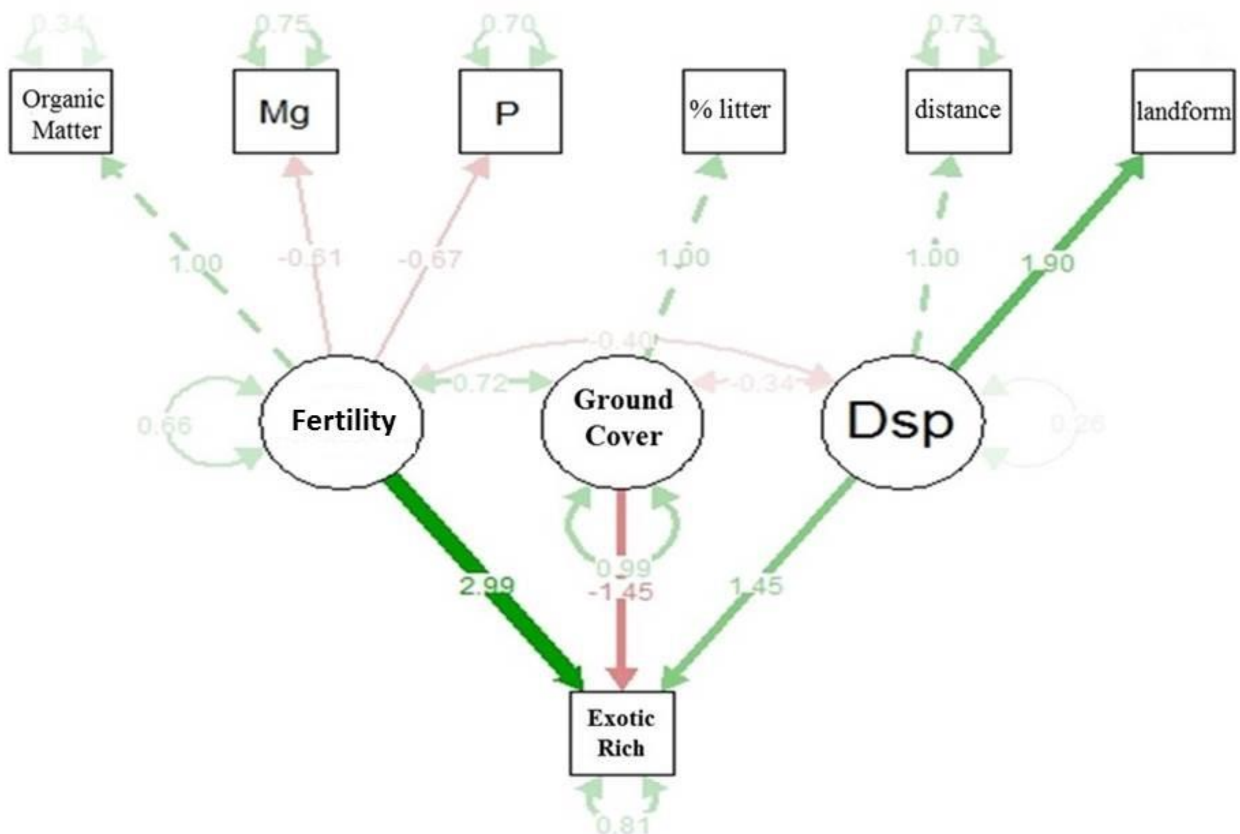

Figure 3.6. Structural equation model showing variables that relate to exotic richness. For a detailed explanation of the structural equation model refer to Fig. 3.2. Exotic species richness was best predicted by organic matter, Mg, P, litter, distance in meters from the closest forest edge, and landform. Goodness-of-fit statistics are: $\chi^2_{10} = 32.40$, $p = 0$, SRMR = 0.071.

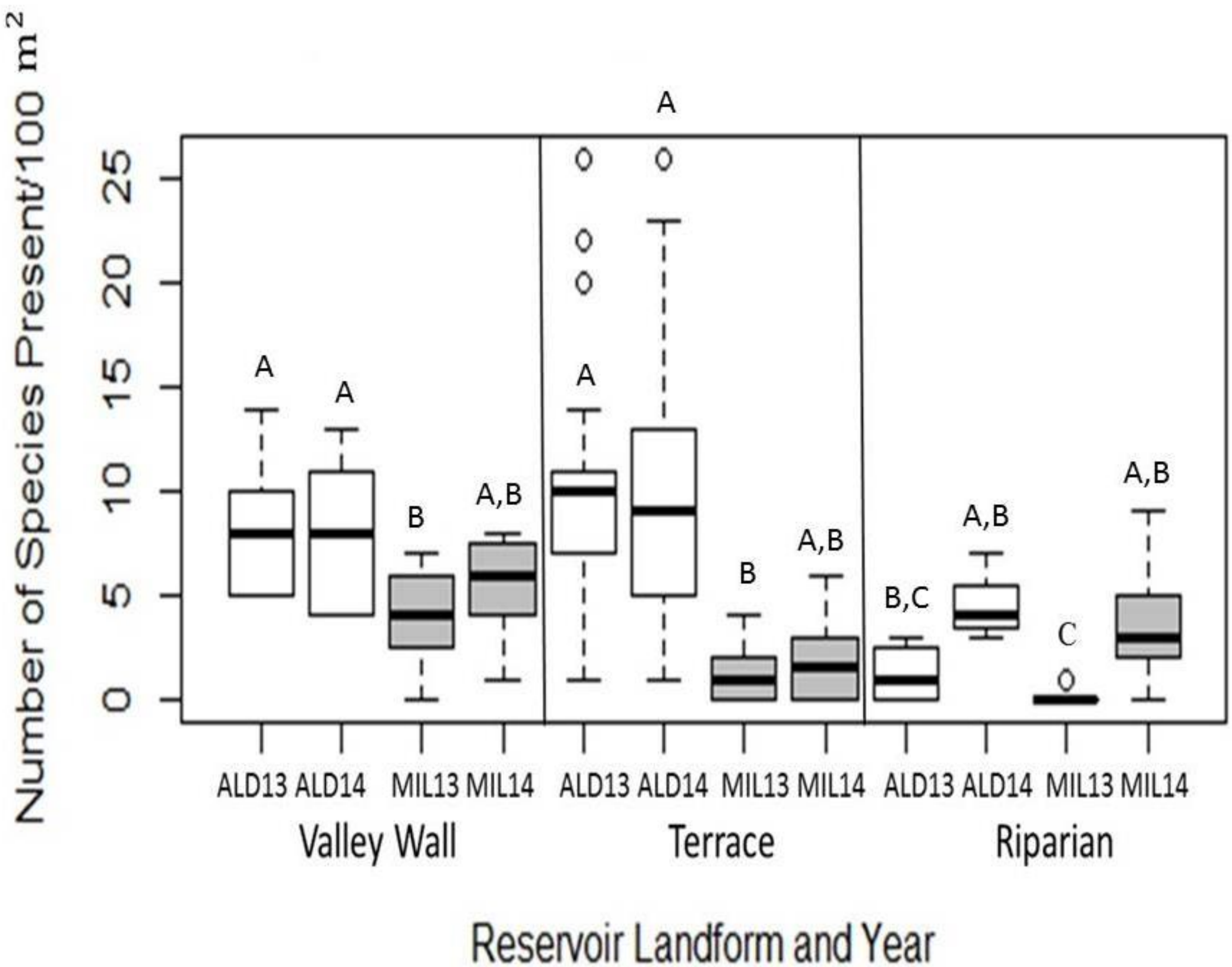

Figure 3.7. Comparison of exotic vascular species richness (Xspp) between reservoir landforms and years within Aldwell and Mills reservoirs along the Elwha River, WA. Xspp refers to the number of vascular species per 100 m^2 plot. Boxplots represent the total number of exotic vascular vegetation species sampled in each reservoir. Whiskers represent the variance in the data and the thick black line in each box represents the median number of species. Different letters are significantly different from each other.

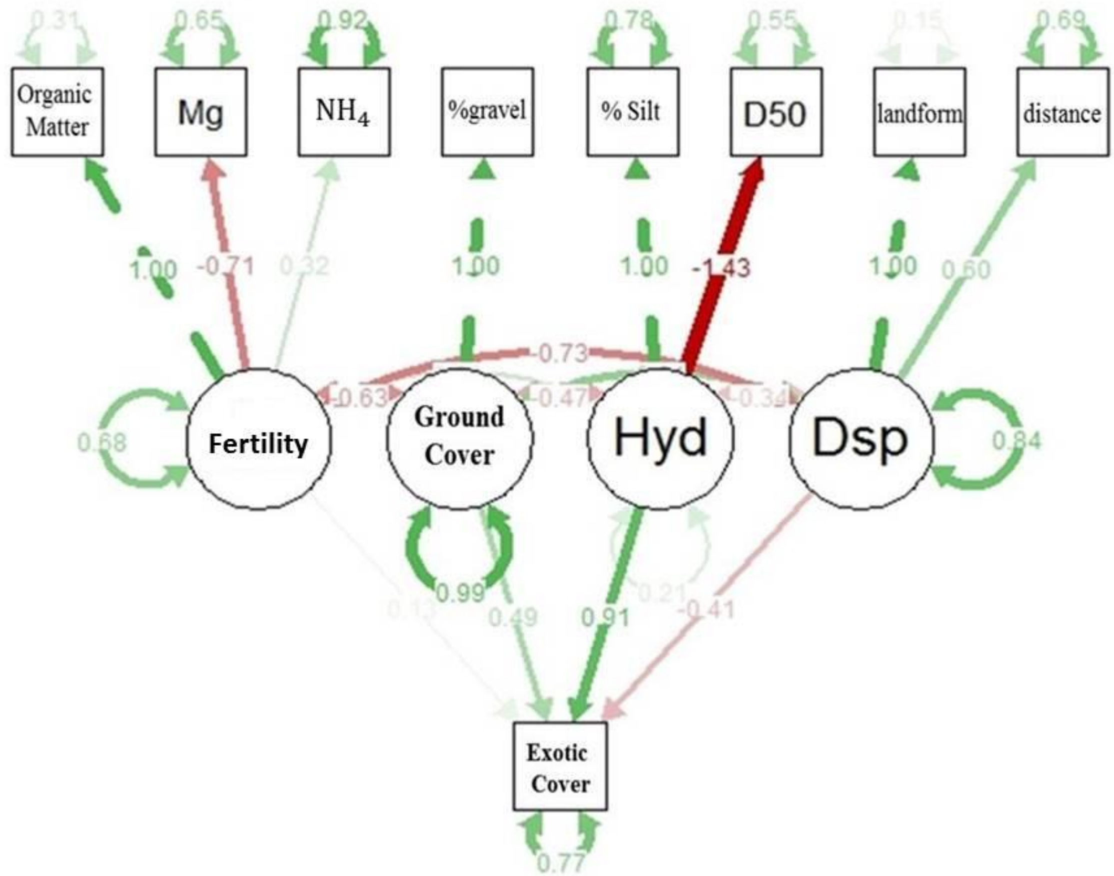

Figure 3.8. Structural equation model showing variables that relate to exotic cover. For a detailed explanation of the structural equation model refer to Fig. 3.2. Exotic species cover is best predicted by organic matter, Mg, NO_4, % gravel, % silt, D50, landform, and distance in meters from the closest forest edge. Goodness-of-fit statistics are: ${\chi^2}_{19}$= 74.68, p = 0, SRMR = 0.08.

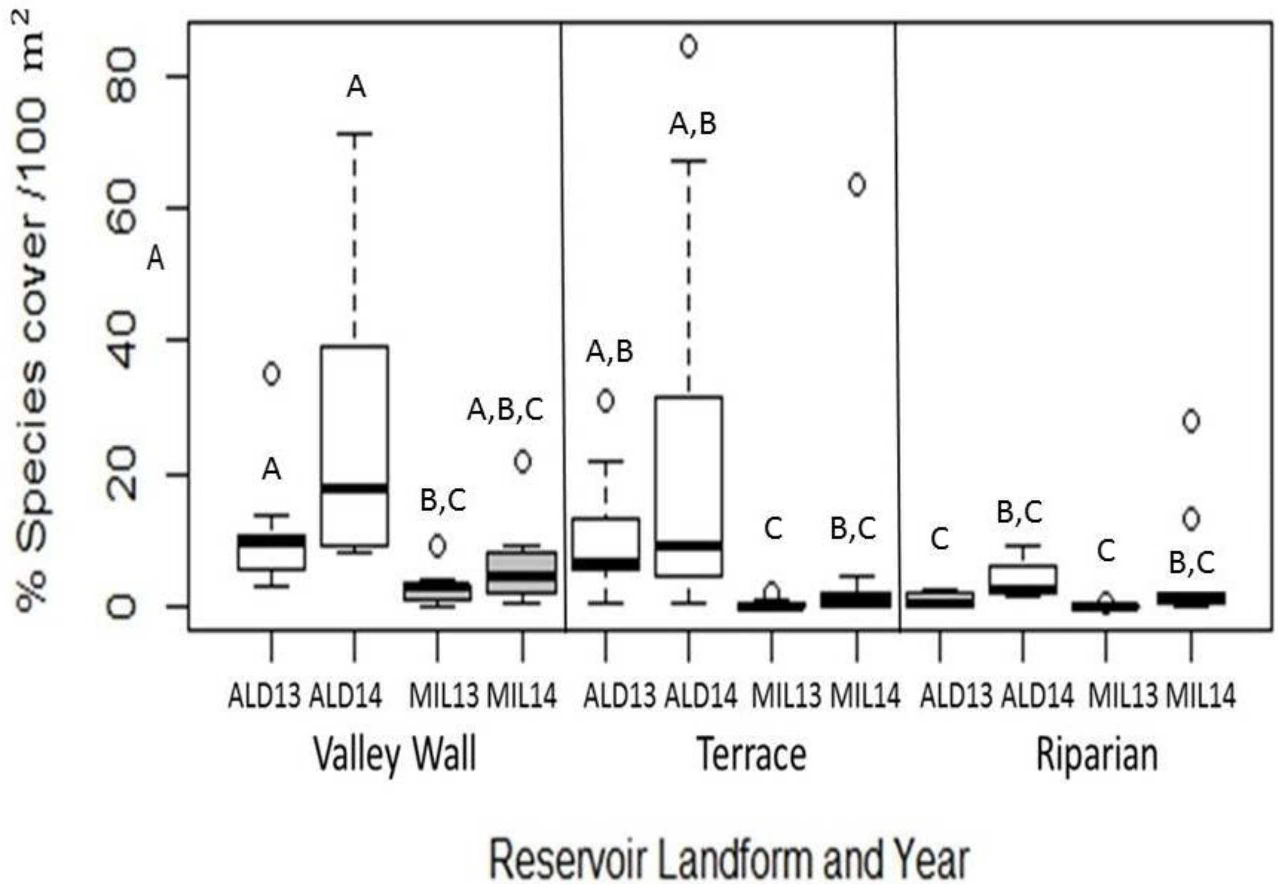

Figure 3.9. Comparison of exotic vascular species cover (Xcov) between reservoir landforms and years within Aldwell and Mills reservoirs along the Elwha River, WA. Boxplots represent total vascular vegetation cover in each reservoir. Whiskers represent the variance in the data and the thick black line in each box represents the median cover value. Different letters are significantly different from each other.

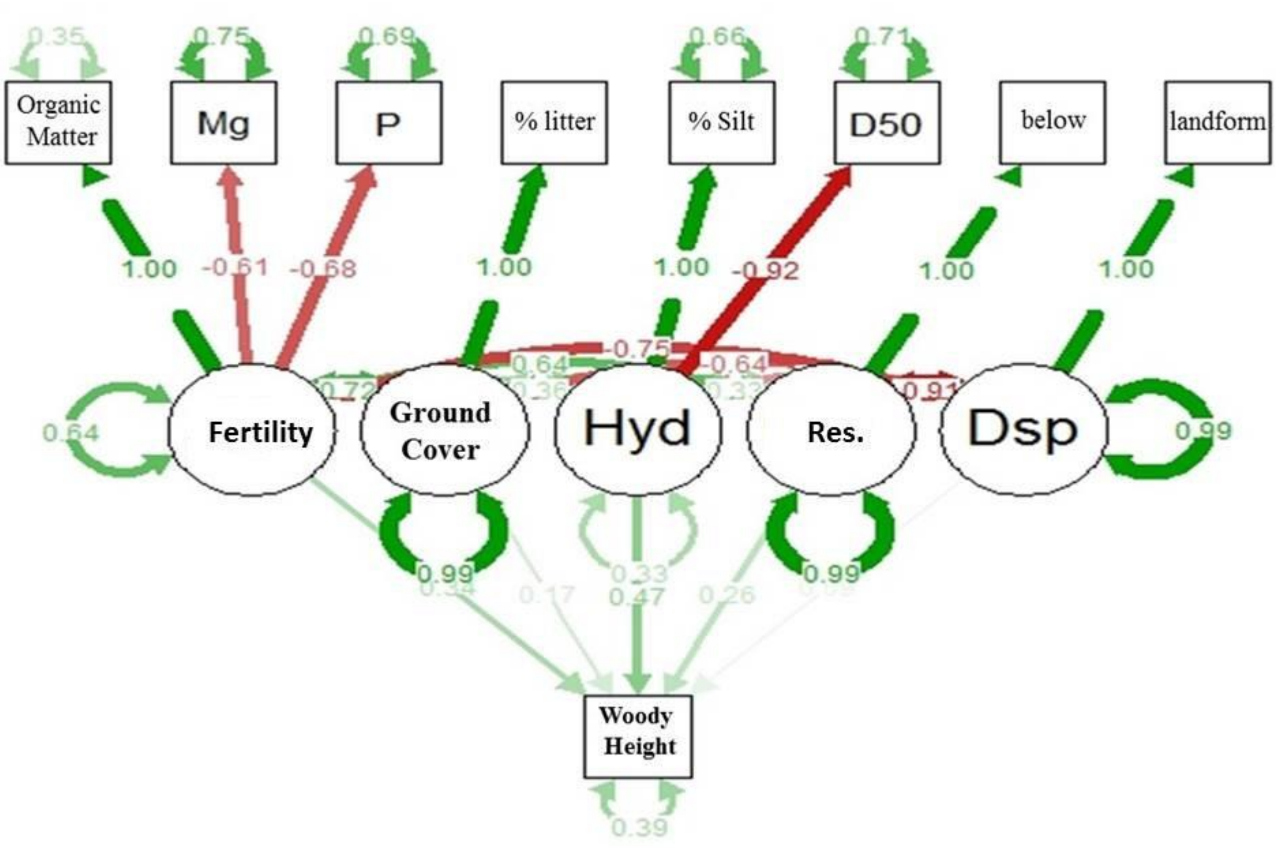

Figure 3.10. Structural equation model showing variables that relate to woody species height. Woody species height is best predicted by organic matter, Mg, P, % litter, % silt, D50, below Glines Canyon dam (Aldwell reservoir), and landform. Goodness-of-fit statistics are: $\chi^2_{16} = 36.02$, $p = 0.003$, SRMR = 0.053.

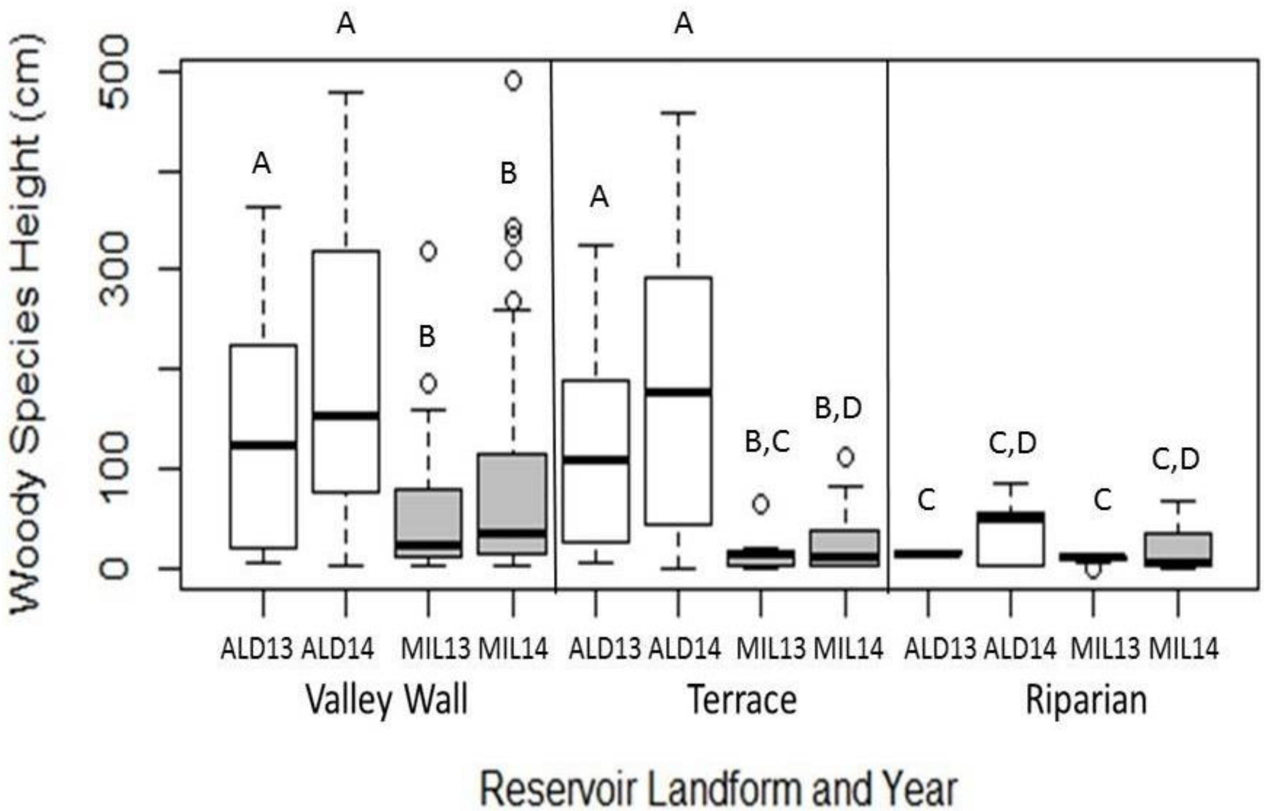

Figure 3.11. Comparison of woody species height between reservoir landforms and years within Aldwell and Mills reservoirs along the Elwha River, WA. Boxplots represent woody species height in each reservoir. Whiskers represent the variance in the data and the thick black line in each box represents the median height value. Different letters are significantly different from each other.

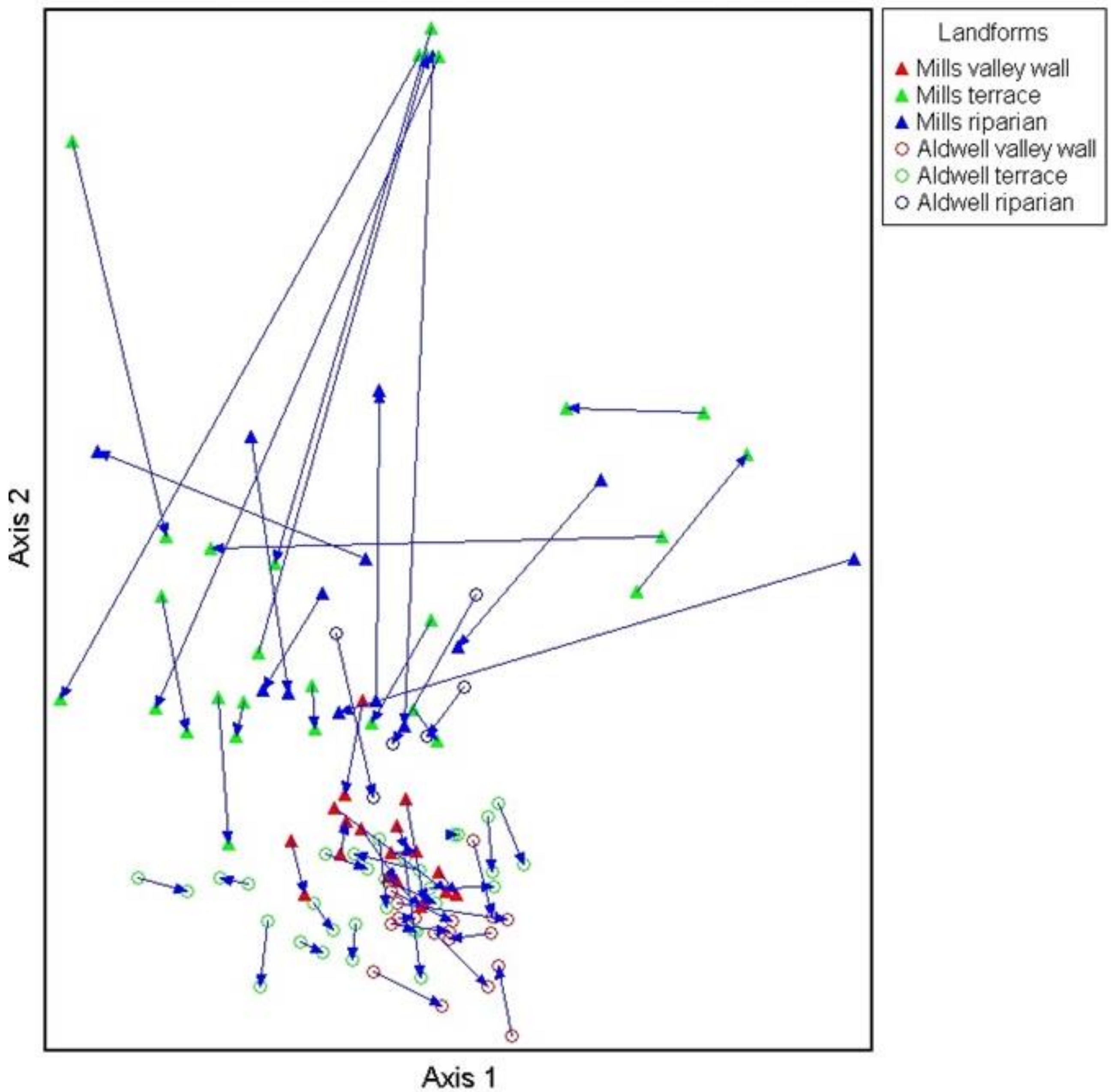

Figure 3.12. NMS ordination biplot (axes 1 and 2) depicting plant community composition differences between Aldwell and Mills reservoirs and among landforms. Blue vectors indicate change in species composition from 2013 to 2014.

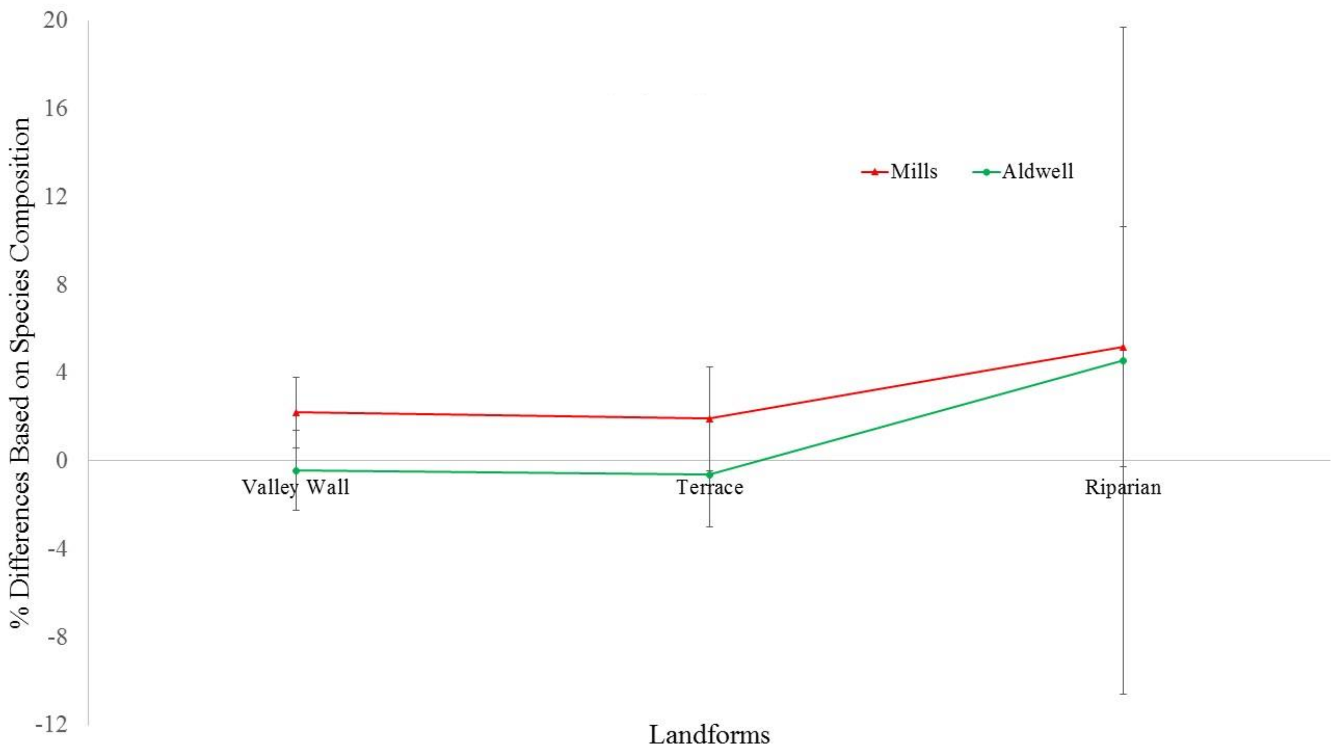

Figure 3.13. Dissimilarity graph derived from ordination shown in Fig. 3.26 depicts percent change between 2013-2014 in vegetation communities. Error bars represent standard errors.

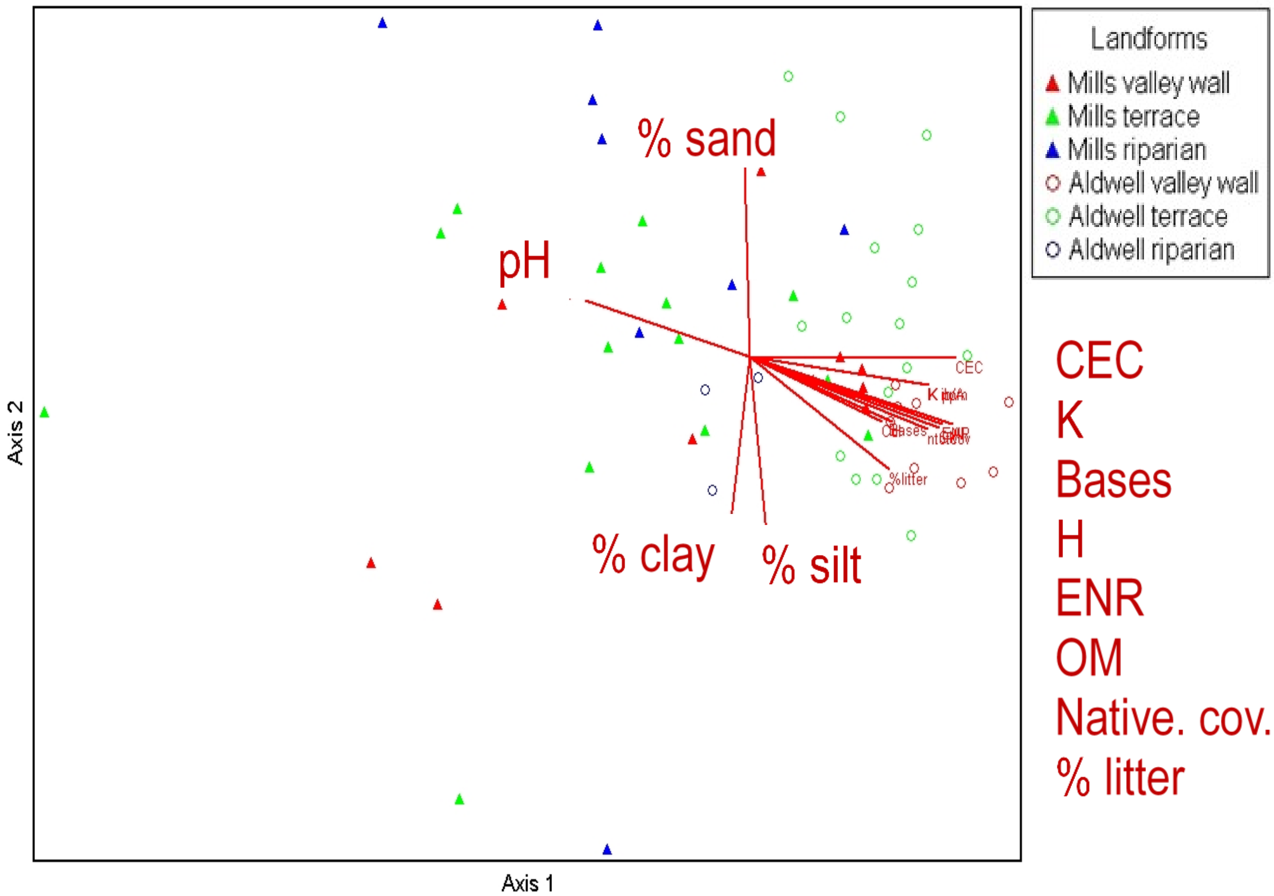

Figure 3.14. NMS plant community composition ordination of species composition in Aldwell and Mills reservoirs in 2014. Plots are grouped by reservoir and landform. Red vectors represent variables correlated with either axis with an $r^2 > 0.20$.

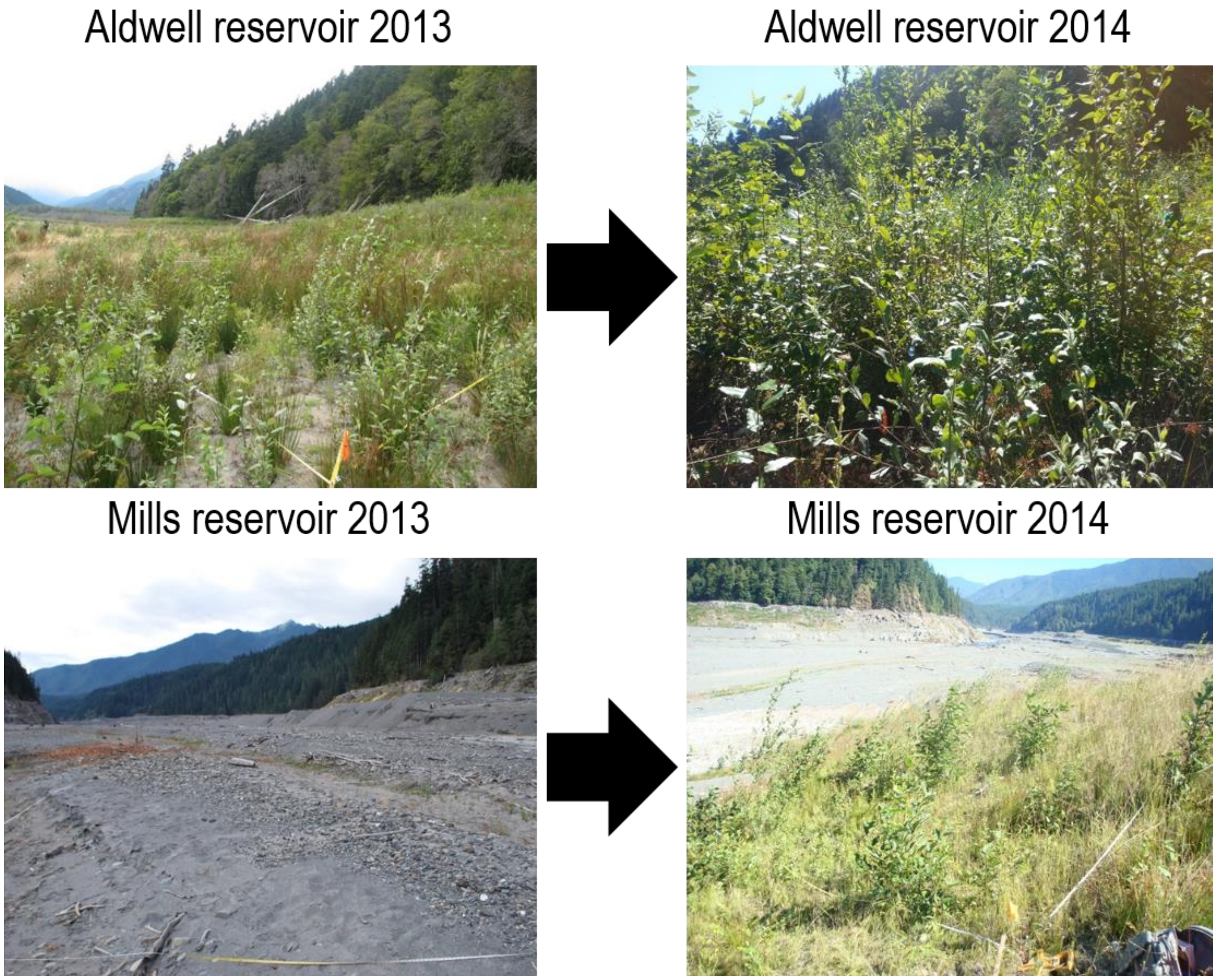

Figure 3.15. Succession pictures depicting changes in species richness, cover, and woody species height along terrace landforms in Aldwell and Mills reservoir.

Appendix I. Master plant lists of plant species sampled on the Elwha River during 2013 and 2014. Species with x represent plants occurring in two or less plots and removed from NMS ordination analysis

EWUCODE	Plant Species	Common Name	Family	Duration	Growth Habit	Native Species Status L(48)
ACERMAC	*Acer macrophyllum*	bigleaf maple	Aceraceae	Perennial	Tree	N
ACHIMIL	*Achillea millefolium*	common yarrow	Asteraceae	Perennial	Forb/herb	N
AGRO1S1	*Agrostis sp.*	bentgrass	Poaceae	Perennial	Graminoid	
AGROCAP	*Agrostis capillaris*	colonial bentgrass	Poaceae	Perennial	Graminoid	I
AGROEXA	*Agrostis exarata*	spike bentgrass	Poaceae	Perennial	Graminoid	N
AGROSP1	*Agrostis sp.*	bentgrass	Poaceae	Perennial	Graminoid	
AGROSTO	*Agrostis stolonifera*	creeping bentgrass	Poaceae	Perennial	Graminoid	I
AIRA1S1	*Aira sp.*	hairgrass	Poaceae	Annual	Graminoid	
AIRACAR	*Aira caryophyllea*	silver hairgrass	Poaceae	Annual	Graminoid	I
AIRAPRA	*Aira praecox*	yellow hairgrass	Poaceae	Annual	Graminoid	I
ALNURUB	*Alnus rubra*	red alder	Betulaceae	Perennial	Tree	N
ANAPMAR	*Anaphalis margaritacea*	western pearly everlasting	Asteraceae	Perennial	Forb/herb	N
ARCTMIN	*Arctium minus*	lesser burdock	Asteraceae	Biennial	Forb/herb	I
ARTESUK	*Artemisia suksdorfii*	coastal wormwood	Asteraceae	Perennial	Forb/herb	N
ASPLVIR	*Asplenium viride*	brightgreen spleenwort	Aspleniaceae	Perennial	Forb/herb	N
ASTE_SP	*Asteracea sp.*	Aster	Asteraceae	Perennial	Forb/herb	
ATHYFIL	*Athyrium filix-femina*	common ladyfern	Dryopteridaceae	Perennial	Forb/herb	N
BARB1S1	*Barbarea sp.*	yellow rocket	Brassicaceae	Biennial, Perennial	Forb/herb	
BRAS_SP	*Brassicaceae sp.*	mustard	Brassicaceae	Biennial	Forb/herb	
BROMINE	*Bromus inermis*	smooth brome	Poaceae	Perennial	Graminoid	I
BROMPAC	*Bromus pacificus*	Pacific brome	Poaceae	Perennial	Graminoid	N
BROMRAC	*Bromus racemosus L.*	bald brome	Poaceae	Perennial	Graminoid	I
BROMVUL	*Bromus vulgaris*	Columbia brome	Poaceae	Perennial	Graminoid	N
CARE1S1	*Carex sp.*	sedge	Cyperaceae	Perennial	Graminoid	
CAREDEW	*Carex deweyana*	Dewey sedge	Cyperaceae	Perennial	Graminoid	N
CAREOBT	*Carex obtusata*	obtuse sedge	Cyperaceae	Perennial	Graminoid	N
CARESP1	*Carex sp.*	sedge	Cyperaceae	Perennial	Graminoid	
CARESTI	*Carex stipata*	awlfruit sedge	Cyperaceae	Perennial	Graminoid	N
CERAARV	*Cerastium arvense*	field chickweed	Caryophyllaceae	Perennial	Forb/herb	N,I
CERASP1	*Cerastium sp.*	chickweed	Caryophyllaceae	Perennial	Forb/herb	
CHAMANG	*Chamerion angustifolium*	fireweed	Onagraceae	Perennial	Forb/herb	N
CINNLAT	*Cinna latifolia*	drooping	Poaceae	Perennial	Graminoid	N

		woodreed					
CIRSARV	*Cirsium arvense*	Canada thistle	Asteraceae	Perennial	Forb/herb	I
CIRSVUL	*Cirsium vulgare*	bull thistle	Asteraceae	Biennial	Forb/herb	I
CLAYPAR	*Claytonia parviflora*	streambank springbeauty	Portulacaceae	Annual	Forb/herb	N
CLAYPER	*Claytonia perfoliata*	miner's lettuce	Portulacaceae	Annual, Perennial	Forb/herb	N
CLAYSIB	*Claytonia sibirica*	Siberian springbeauty	Portulacaceae	Annual, Perennial	Forb/herb	N
COLLHET	*Collomia heterophylla*	variableleaf collomia	Polemoniaceae	Annual	Forb/herb	N
CREPCAP	*Crepis capillaris*	smooth hawksbeard	Asteraceae	Annual, Biennial	Forb/herb	I
CYTISCO	*Cytisus scoparius*	Scotch broom	Fabaceae	Perennial	Shrub	I
DACTGLO	*Dactylis glomerata*	orchardgrass	Poaceae	Perennial	Graminoid	I
DESCELO	*Deschampsia elongata*	slender hairgrass	Poaceae	Perennial	Graminoid	N
DIGIPUR	*Digitalis purpurea*	purple foxglove	Scrophulariacea e	Biennial	Forb/herb	I
ELYMGLA G	*Elymus glaucus*	blue wildrye	Poaceae	Perennial	Graminoid	N
EPILBRA	*Epilobium brachycarpum*	tall annual willowherb	Onagraceae	Annual	Forb/herb	N
EPILCIL	*Epilobium ciliatum*	fringed willowherb	Onagraceae	Perennial	Forb/herb	N
EPILMIN	*Epilobium minutum*	chaparral willowherb	Onagraceae	Annual	Forb/herb	N
EQUIARV	*Equisetum arvense*	field horsetail	Equisetaceae	Perennial	Forb/herb	N
EQUISYL	*Equisetum sylvaticum*	woodland horsetail	Equisetaceae	Perennial	Forb/herb	N
ERECMIN	*Erechtites minima*	coastal burnweed	Asteraceae	Annual, Perennial	Forb/herb	I
ERIOLAN	*Eriophyllum lanatum*	common woolly sunflower	Asteraceae	Perennial	Subshrub, Forb/herb	N
FEST1S1	*Festuca sp.*	fescue	Poaceae	Perennial	Graminoid	
FESTRUB	*Festuca rubra*	red fescue	Poaceae	Perennial	Graminoid	N
FRAGVES	*Fragaria vesca*	woodland strawberry	Rosaceae	Perennial	Forb/herb	N
FRAGVIR	*Fragaria virginiana*	Virginia strawberry	Rosaceae	Perennial	Forb/herb	N
GALIAPA	*Galium aparine*	stickywilly	Rubiaceae	Annual	Vine, Forb/herb	N
GALITRF	*Galium triflorum*	fragrant bedstraw	Rubiaceae	Perennial	Forb/herb, Vine	N
GALITRL	*Galium trifidum*	threepetal bedstraw	Rubiaceae	Perennial	Vine, Forb/herb	N
GERAROB	*Geranium robertianum*	Robert geranium	Geraniaceae	Annual, Biennial	Forb/herb	N,I
GLYCELA	*Glyceria elata*	fowl mannagrass	Poaceae	Perennial	Graminoid	N
HIER1DA	*Hieracium sp.*	hawkweed	Asteraceae	Perennial	Forb/herb	
HOLCLAN	*Holcus lanatus*	common velvetgrass	Poaceae	Perennial	Graminoid	I
HOLODIS	*Holodiscus discolor*	oceanspray	Rosaceae	Perennial	Shrub	N
HYPEPER	*Hypericum perforatum*	common St. Johnswort	Clusiaceae	Perennial	Forb/herb	I
HYPORAD	*Hypochaeris radicata*	hairy cat's ear	Asteraceae	Perennial	Forb/herb	I

IMPACAP	*Impatiens capensis*	jewelweed	Balsaminaceae	Annual	Forb/herb	N
JUNC1S1	*Juncus sp.*	rush	Juncaceae		Graminoid	
JUNC1S2	*Juncus sp.*	rush	Juncaceae		Graminoid	
JUNCACU	*Juncus acuminatus*	tapertip rush	Juncaceae	Perennial	Graminoid	N
JUNCART	*Juncus articulatus*	jointleaf rush	Juncaceae	Perennial	Graminoid	N
JUNCBAL	*Juncus balticus*	Baltic rush	Juncaceae	Perennial	Graminoid	N
JUNCBOL	*Juncus bolanderi*	Bolander's rush	Juncaceae	Perennial	Graminoid	N
JUNCBUF	*Juncus bufonius*	toad rush	Juncaceae	Annual	Graminoid	N
JUNCEFF	*Juncus effusus*	common rush	Juncaceae	Annual	Graminoid	N
JUNCENS	*Juncus ensifolius*	swordleaf rush	Juncaceae	Perennial	Graminoid	N
JUNCMER	*Juncus mertensianus*	Mertens' rush	Juncaceae	Perennial	Graminoid	N
LATHLAT	*Lathyrus latifolius*	perennial pea	Fabaceae	Perennial	Vine, Forb/herb	I
LEUCVUL	*Leucanthemum vulgare*	oxeye daisy	Asteraceae	Perennial	Forb/herb	I
LOTU1S1	*Lotus sp.*	trefoil	Fabaceae	Perennial	Forb/herb	
LOTUCOR	*Lotus corniculatus*	bird's-foot trefoil	Fabaceae	Perennial	Forb/herb	I
LUPIRIV	*Lupinus rivularis*	riverbank lupine	Fabaceae	Perennial	Subshrub, Forb/herb	N
LUZUPAR	*Luzula parviflora*	smallflowered woodrush	Juncaceae	Perennial	Graminoid	N
MENTARV	*Mentha arvensis*	wild mint	Lamiaceae	Perennial	Forb/herb	N
MIMUGUT	*Mimulus guttatus*	seep monkeyflowe r	Scrophulariacea e	Annual, Perennial	Forb/herb	N
MIMULEW	*Mimulus lewisii*	purple monkeyflowe r	Scrophulariacea e	Perennial	Forb/herb	N
MYCEMUR	*Mycelis muralis*	wall-lettuce	Asteraceae	Annual	Forb/herb	I
MYOSLAX	*Myosotis laxa*	bay forget-me-not	Boraginaceae	Annual, Biennial, Perennial	Forb/herb	N
OENASAR	*Oenanthe sarmentosa*	water parsely	Apiaceae	Perennial	Forb/herb	N
OSMOBER	*Osmorhiza berteroi*	sweetcicely	Apiaceae	Perennial	Forb/herb	N
PETAFRP	*Petasites frigidus*	arctic sweet coltsfoot	Asteraceae	Perennial	Forb/herb	N
PHALARU	*Phalaris arundinacea*	reed canarygrass	Poaceae	Perennial	Graminoid	I
PLANLAN	*Plantago lanceolata*	narrowleaf plantain	Plantaginaceae	Annual, Biennial, Perennial	Forb/herb	I
PLANMAJ	*Plantago major*	common plantain	Plantaginaceae	Perennial	Forb/herb	I
POA_1S2	*Poaceae sp.*	grass	Poaceae		Graminoid	
POA_ANN	*Poa annua*	annual bluegrass	Poaceae	Annual	Graminoid	I
POA_COM	*Poa compressa*	Canada bluegrass	Poaceae	Perennial	Graminoid	I
POA_TRV	*Poa trivialis*	rough bluegrass	Poaceae	Perennial	Graminoid	I
POLYMIN	*Polygonum minimum*	broadleaf knotweed	Polygonaceae	Annual	Forb/herb	N
POLYPAR	*Polygonum paronychia*	beach knotweed	Polygonaceae	Perennial	Subshrub	N
POPUBALT	*Populus balsamifera ssp.*	black	Salicaceae	Perennial	Tree	N

	trichocarpa	cottonwood				
PRUN1S1	*Prunus sp.*	plum	Rosaceae	Perennial	Tree	
PRUNEMA	*Prunus emarginata*	bitter cherry	Rosaceae	Perennial	Tree	N
PRUNVUL	*Prunella vulgaris L.*	common selfheal	Lamiaceae	Perennial	Forb/herb	N
PSEUMEN	*Pseudotsuga menziesii*	Douglas-fir	Pinaceae	Perennial	Tree	N
RANUOCC	*Ranunculus occidentalis*	western buttercup	Ranunculaceae	Perennial	Forb/herb	N
RANUREP	*Ranunculus repens*	creeping buttercup	Ranunculaceae	Perennial	Forb/herb	I
RORI1S1	*Rorippa Scop.*	yellowcress	Brassicaceae		Forb/herb	
RUBUDIS	*Rubus discolor*	Himalayan blackberry	Rosaceae	Perennial	Subshrub	I
RUBULEU	*Rubus leucodermis*	whitebark raspberry	Rosaceae	Perennial	Vine, Subshrub	N
RUBUPAR	*Rubus parviflorus*	thimbleberry	Rosaceae	Perennial	Subshrub	N
RUBUSPE	*Rubus spectabilis*	salmonberry	Rosaceae	Perennial	Vine, Subshrub	N
RUBUURS	*Rubus ursinus*	California blackberry	Rosaceae	Perennial	Subshrub	N
RUMEACE	*Rumex acetosa*	garden sorrel	Polygonaceae	Perennial	Forb/herb	I
RUMECRI	*Rumex crispus*	curly dock	Polygonaceae	Perennial	Forb/herb	I
SAGIMAX	*Sagina maxima*	stickystem pearlwort	Caryophyllaceae	Annual, Biennial, Perennial	Forb/herb	N
SAGIPRO	*Sagina procumbens*	birdeye pearlwort	Caryophyllaceae	Perennial	Forb/herb	I
SALILUC	*Salix lucida*	shining willow	Salicaceae	Perennial	Tree, Shrub	N
SALISIT	*Salix sitchensis*	Sitka willow	Salicaceae	Perennial	Tree, Shrub	N
SEDU1S1	*Sedum sp.*	stonecrop	Crassulaceae		Forb/herb	
SEDUSPA	*Sedum spathulifolium*	broadleaf stonecrop	Crassulaceae	Perennial	Forb/herb	N
SENE1S1	*Senecio sp.*	ragwot	Asteraceae		Forb/herb	
SENEJAC	*Senecio jacobaea*	stinking willie	Asteraceae	Perennial	Forb/herb	I
SENESYL	*Senecio sylvaticus*	woodland ragwort	Asteraceae	Annual	Forb/herb	I
SENEVUL	*Senecio vulgaris*	old-man-in-the-Spring	Asteraceae	Annual, Biennial	Forb/herb	I
SONCASP	*Sonchus asper*	spiny sowthistle	Asteraceae	Annual	Forb/herb	I
SPERCAN	*Spergularia canadensis*	Canadian sandspurry	Caryophyllaceae	Annual	Forb/herb	N
STACCHA	*Stachys chamissonis*	coastal hedgenettle	Lamiaceae	Perennial	Forb/herb	N
STELCAL	*Stellaria calycantha*	northern starwort	Caryophyllaceae	Annual, Perennial	Forb/herb	N
STELCRI	*Stellaria crispa*	curled starwort	Caryophyllaceae	Annual, Perennial	Forb/herb	N
TARA1S1	*Taraxacum sp.*	dandelion	Asteraceae	Perennial	Forb/herb	
TARAOFF	*Taraxacum officinale*	common dandelion	Asteraceae		Forb/herb	N,I
TELLGRA	*Tellima grandiflora*	bigflower tellima	Saxifragaceae	Perennial	Forb/herb	N
THUJPLI	*Thuja plicata*	western redcedar	Cupressaceae	Perennial	Tree	N

TOLMMEN	*Tolmiea menziesii*	youth on age	Saxifragaceae	Perennial	Forb/herb	N
TRIF_SP	*Trifolium sp.*	clover	Fabaceae		Forb/herb	
TRIF1S1	*Trifolium sp.*	clover	Fabaceae		Forb/herb	
TRIFDUB	*Trifolium dubium*	suckling clover	Fabaceae	Annual	Forb/herb	I
TRIFPRA	*Trifolium pratense*	red clover	Fabaceae	Biennial, Perennial	Forb/herb	I
TRIFREP	*Trifolium repens*	white clover	Fabaceae	Perennial	Forb/herb	I
TSUGHET	*Tsuga heterophylla*	western hemlock	Pinaceae	Perennial	Tree	N
URTIDIO	*Urtica dioica*	stinging nettle	Urticaceae	Perennial	Forb/herb	N,I
VEROAME	*Veronica americana*	American speedwell	Scrophulariacea e	Perennial	Forb/herb	N
VEROARV	*Veronica arvensis*	corn speedwell	Scrophulariacea e	Annual	Forb/herb	I
VICIHIR	*Vicia hirsuta*	tiny vetch	Fabaceae	Annual	Vine, Forb/herb	I
VICISAT	*Vicia sativa*	garden vetch	Fabaceae	Annual	Vine, Forb/herb	I
VICISP1	*Vica sp.*	vetch	Fabaceae		Vine, Forb/herb	
VULPMYU	*Vulpia myuros*	annual fescue	Poaceae	Annual	Graminoid	I
ABIEGRA	*Abies grandis x*	gradn fir	Pinaceae	Perennial	Tree	N
ACERCIR	*Acer circinatum x*	vine maple	Aceraceae	Perennial	Tree, Shrub, Vine	N
AGOSAUR	*Agoseris aurantiaca x*	orange agoseris	Asteraceae	Perennial	Subshrub, Forb/herb	N
ALOPAEQ	*Alopecurus aequalis x*	shortawn foxtail	Poaceae	Perennial	Graminoid	N
ALOPGEN	*Alopecurus geniculatus x*	water foxtail	Poaceae	Perennial	Graminoid	I
ANGEGEN	*Angelica genuflexa x*	kneeling angelica	Apiaceae	Perennial	Forb/herb	N
APIA_SP	*Apiaceae sp. x*		Apiaceae	Perennial	Forb/herb	
AQUIFOR	*Aquilegia formosa x*	western columbine	Ranunculaceae	Perennial	Forb/herb	N
ARABHIR	*Arabis hirsuta x*	hairy rockcress	Brassicaceae	Annual, Biennial, Perennial	Forb/herb	N
BARBORT	*Barbarea orthoceras x*	American yellow rocket	Brassicaceae	Biennial, Perennial	Forb/herb	N
BARBVUL	*Barbarea vulgaris x*	garden yellowrocket	Brassicaceae	Biennial	Forb/herb	I
BROMSIT	*Bromus sitchensis x*	Alaska brome	Poaceae	Perennial	Graminoid	N
BROM1S1	*Bromus sp. x*		Poaceae		Graminoid	
CALASES	*Calamagrostis sesquiflora x*	one and a half flower reedgrass	Poaceae	Perennial	Graminoid	N
CARDOLI	*Cardamine oligosperma x*	umbel bittercress	Brassicaceae	Annual, Biennial, Perennial	Forb/herb	N
CARD1S1	*Cardamine sp. x*		Brassicaceae	Annual, Biennial, Perennial	Forb/herb	
CAREAPE	*Carex aperta x*	Columbian sedge	Cyperaceae	Perennial	Graminoid	N

CARELEP	*Carex leporina* x	bristlystalked sedge	Cyperaceae	Perennial	Graminoid	N
CAREPAC	*Carex pachystachya* x	chamisso sedge	Cyperaceae	Perennial	Graminoid	N
CAREPHY	*Carex phyllomanica* x	star sedge	Cyperaceae	Perennial	Graminoid	N
CAREPYR	*Carex pyrenaica* x	Pyrenean sedge	Cyperaceae	Perennial	Graminoid	N
CAREROS	*Carex rostrata* x	beaked sedge	Cyperaceae	Perennial	Graminoid	N
CARESP1	*Carex sp.* x		Cyperaceae	Perennial	Graminoid	
CARESP2	*Carex sp.* x		Cyperaceae	Perennial	Graminoid	
CARESP3	*Carex sp.* x		Cyperaceae	Perennial	Graminoid	
CARESP4	*Carex sp.* x		Cyperaceae	Perennial	Graminoid	
CARETUM	*Carex tumulicola* x	splitawn sedge	Cyperaceae	Perennial	Graminoid	N
CERA1S1	*Cerastium sp.* x		Caryophyllaceae	Perennial	Forb/herb	
CINNLAT	*Cinna latifolia* x	drooping woodreed	Poaceae	Perennial	Graminoid	N
CIRCALP	*Circaea alpina* x	small enchanter's nightshade	Onagraceae	Perennial	Forb/herb	N
COLLGRA	*Collomia grandiflora* x					N
COLL1S1	*Collomia species* x	grand collomia	Polemoniaceae	Annual	Forb/herb	
CONYCAN	*Conyza canadensis* x	Canadian horseweed	Asteraceae	Annual, Biennial	Forb/herb	N
CRATDOU	*Crataegus douglasii* x	black hawthorn	Rosaceae	Perennial	Tree, Shrub	N
CRYPINT	*Cryptantha intermedia* x	Clearwater cryptantha	Boraginaceae	Annual	Forb/herb	N
DICEFOR	*Dicentra formosa* x	Pacific bleeding heart	Fumariaceae	Perennial	Forb/herb	N
DICO_S1	*Dicot sp.* x					
DICO_SP	*Dicot sp.* x					
ELEOPAL	*Eleocharis palustris* x	common spikerush	Cyperaceae	Perennial	Graminoid	N
EPIL1S1	*Epilobium sp.* x		Onagraceae	Perennial	Forb/herb	
EPIL1S2	*Epilobium sp.* x		Onagraceae	Perennial	Forb/herb	
EQUIHYE	*Equisetum hyemale* x	scouringrush horsetail	Equisetaceae	Perennial	Forb/herb	N
EQUI1S1	*Equisetum sp.* x		Equisetaceae	Perennial	Forb/herb	
ERIGPHI	*Erigeron philadelphicus* x	Philadelphia fleabane	Asteraceae	Biennial, Perennial	Forb/herb	N
FERN1	*fern sp.* x		Dryopteridaceae	Perennial	Forb/herb	
FERN2	*fern sp.* x		Dryopteridaceae	Perennial	Forb/herb	
FESTOCC	*Festuca occidentalis* x	western fescue	Poaceae	Annual	Graminoid	N
GALI1S1	*Galium sp.* x		Rubiaceae	Perennial	Vine, Forb/herb	
GALI1S2	*Galium sp.* x		Rubiaceae	Perennial	Vine, Forb/herb	
GNAPMIC	*Gnaphalium microcephalum* x	Wright's cudweed	Asteraceae	Biennial, Perennial	Forb/herb	N

GYMNDRY	*Gymnocarpium dryopteris x*	western oakfern	Dryopteridaceae	Perennial	Forb/herb	N
HESPMAT	*Hesperis matronalis x*	dames rocket	Brassicaceae	Biennial, Perennial	Forb/herb	I
HIERALB	*Hieracium albiflorum x*	white hawkweed	Asteraceae	Perennial	Forb/herb	N
IMPAECA	*Impatiens ecalcarata x*	sourless touch-me-not	Balsaminaceae	Annual	Forb/herb	N
IMPA1S1	*Impatiens sp. x*		Balsaminaceae	Annual	Forb/herb	
JUNCSUP	*Juncus supiniformis x*	hairy leaf rush	Juncaceae	Perennial	Graminoid	N
JUNCTEN	*Juncus tenuis x*	forked rush	Juncaceae	Perennial	Graminoid	N
LAPCOM	*Lapsana communis x*	common nipplewort	Asteraceae	Annual	Forb/herb	I
LINNBOR	*Linnaea borealis x*	twinflower	Caprifoliaceae	Perennial	Forb/herb, Subshrub	N
LUZUMUL	*Luzula multiflora x*	common woodrush	Juncaceae	Perennial	Graminoid	N
LYCOUNI	*Lycopus uniflorus x*	northern bugleweed	Lamiaceae	Perennial	Forb/herb	N
MADIGRA	*Madia gracilis x*	grassy tarweed	Asteraceae	Annual	Forb/herb	N
MATRMAT	*Matricaria matricarioides x*	disc mayweed	Asteraceae	Annual	Forb/herb	I
MEDILUP	*Medicago lupulina x*	black medick	Fabaceae	Annual, Perennial	Forb/herb	I
MENTPIP	*Mentha piperita x*	water mint	Lamiaceae	Perennial	Forb/herb	I
MIMUMOS	*Mimulus moschatus x*	muskflower	Scrophulariacea e	Perennial	Forb/herb	N
MIMU1S1	*Mimulus sp. x*		Scrophulariacea e	Perennial	Forb/herb	
NEMOPAR	*Nemophila parviflora x*	smallflower nemophila	Hydrophyllacea e	Annual	Forb/herb	N
OEMLCER	*Oemleria cerasiformis x*	Indian plum	Rosaceae	Perennial	Tree, Shrub	N
PHEL1S1	*Phleum sp. x*		Poaceae	Perennial	Graminoid	
POA_PAL	*Poa palustris x*	fowl bluegrass	Poaceae	Perennial	Graminoid	N
POA_PRA	*Poa pratensis x*	Kentucky bluegrass	Poaceae	Perennial	Graminoid	N,I
POA_1S1	*Poaceae sp. x*		Poaceae	Perennial	Graminoid	
POA_1S2	*Poaceae sp. x*		Poaceae	Perennial	Graminoid	
POLY1S1	Polypodium L. X					
POLYGLY	*Polypodium glycyrrhiza x*	licorice fern	Polypodiaceae	Perennial	Forb/herb	N
RANU1S1	*Ranunculus sp. x*		Ranunculaceae	Perennial	Forb/herb	
RIBELAC	*Ribes lacustre x*	prickly currant	Grossulariaceae	Perennial	Shrub	N
RORIISL	*Rorippa islandica x*	northern marsh yellowcress	Brassicaceae	Annual, Biennial, Perennial	Forb/herb	I
ROSAGYM	*Rosa gymnocarpa x*	dwarf rose	Rosaceae	Perennial	Shrub, Subshrub	N
ROSANUT	*Rosa nutkana x*	bristly Nootka rose	Rosaceae	Perennial	Subshrub	N
RUME1S1	*Rumex sp. x*		Polygonaceae	Perennial	Forb/herb	

SAGIAPE	*Sagina apetala* x	annual pearlwort	Caryophyllaceae	Annual	Forb/herb	I
SAGI1S1	*Sagina sp.* x		Caryophyllaceae	Annual	Forb/herb	
SALI1S1	*Salix sp.* x		Salicaceae	Perennial	Tree/Shrub	
SAMBNIG	*Sambucus nigra* x	blue elderberry	Caprifoliaceae	Perennial	Shrub, Tree	N,I
SAMBRAC	*Sambucus racemosa* x	red elderberry	Caprifoliaceae	Perennial	Tree, Shrub	N
SEDU1S1	*Sedum sp.* x		Crassulaceae	Perennial	Forb/herb	
SENE1S1	*Senecio sp.* x		Asteraceae	Perennial	Forb/herb	
SENE1S2	*Senecio sp.* x		Asteraceae	Perennial	Forb/herb	
SOLICAN	*Solidago canadensis* x	shorthair goldenrod	Asteraceae	Perennial	Forb/herb	N
SPERCAN	*Spergularia canadensis* x	Canadian sandspurry	Caryophyllaceae	Annual	Forb/herb	N
SPERRUB	*Spergularia rubra* x	red sandspurry	Caryophyllaceae	Annual, Perennial	Forb/herb	I
STAC1S1	*Stachys sp.* x		Lamiaceae	Perennial	Forb/herb	
TARA1S1	*Taraxacum sp.* x		Asteraceae	Perennial	Forb/herb	
TIARTRI	*Tiarella trifoliata* x	threeleaf foamflower	Saxifragaceae	Perennial	Forb/herb	N
TRIEBOR	*Trientalis borealis* x	broadleaf starflower	Primulaceae	Perennial	Forb/herb	N
TRIFCAM	*Trifolium campestre* x	field clover	Fabaceae	Annual, Biennial	Forb/herb	I
VERBTHA	*Verbascum thapsus* x	common mullein	Scrophulariacea e	Biennial	Forb/herb	I
VICIAME	*Vicia americana* x	American vetch	Fabaceae	Perennial	Vine, Forb/herb	N
VICINIG	*Vicia nigricans* x	giant vetch	Fabaceae	Perennial	Vine, Forb/herb	N
VICI1S1	*Vicia sp.* x		Fabaceae	Perennial	Vine, Forb/herb	
VIOL1S1	*Viola sp.* x		Violaceae	Perennial	Forb/herb	

Appendix II. Plots sampled during one season and removed from NMS Ordination Analysis

Removed Plots	Year	Landform
ALD2300	2013	terrace
ALD4800	2013	riparian
MIL1100	2013	valley wall
MIL1200	2013	valley wall
MIL2100	2013	terrace
MIL2500	2013	terrace
MIL31000	2013	terrace
MIL3900	2013	terrace
MIL4550	2014	riparian

Appendix III. Reservoir plant community indicator species analysis corresponding with Figure 3.12. Refer to Appendix I for codes.

		Observed Indicator value (IV)	IV from Randomized Groups		
plant code	reservoir		Mean	S.Dev	P
EPILBRA	Mills	34.5	27.3	3.33	0.033
PSEUMEN	Mills	30	22.7	3.42	0.037
PHALARU	Aldwell	68.6	20.9	3.25	0.001
SALISIT	Aldwell	65.6	41	3.25	0.001
JUNCEFF	Aldwell	63.9	29.1	3.2	0.001
POPUBALT	Aldwell	63.4	41.8	3.1	0.001
JUNCBAL	Aldwell	54.8	26.5	3.33	0.001
ALNURUB	Aldwell	53.6	32.9	3.41	0.001
EQUIARV	Aldwell	53.6	36.8	3.47	0.001
EPILCIL	Aldwell	53.2	41.5	3	0.003
AGROSTO	Aldwell	52.4	23.1	3.26	0.001
RANUREP	Aldwell	50.8	17.3	3.07	0.001
AGROEXA	Aldwell	45.8	37.5	3.25	0.012
HYPORAD	Aldwell	43.7	16.3	2.97	0.001
ACERMAC	Aldwell	42.2	20.5	3.29	0.001
CHAMANG	Aldwell	39.9	20.1	3.35	0.001
RUBUSPE	Aldwell	37.8	18.9	3.16	0.001
DESCELO	Aldwell	37.6	37.4	3.32	0.414
CIRSVUL	Aldwell	37.3	18.5	3.05	0.001
CIRSARV	Aldwell	37.1	18.7	3.21	0.001
JUNCBOL	Aldwell	33.4	18.2	3.25	0.001
AGROCAP	Aldwell	30.7	14	2.86	0.001
RUMECRI	Aldwell	27.8	18.2	3.17	0.016
SALILUC	Aldwell	26.4	16	3.14	0.01
MYCEMUR	Aldwell	25.3	14	2.95	0.005
ARTESUK	Aldwell	24.8	13.7	2.88	0.005
LEUCVUL	Aldwell	23.2	8.3	2.22	0.001
TARAOFF	Aldwell	22.3	9.7	2.41	0.001
SONCASP	Aldwell	22.2	9.7	2.48	0.004

Appendix IV. Variance explained (as r^2 values) by the axes in each of the NMS ordinations. Total variance explained by each ordination can be found in the cumulative column. Corresponds with Figure 3.12.

	R Squared	
Axis	Increment	Cumulative
1	.574	.574
2	.205	.779

Increment and cumulative R-squared were adjusted for any lack
of orthogonality of axes.

Axis pair	r	Orthogonality, % = $100(1-r^2)$
1 vs 2	-0.022	100.0

Number of entities = 60
Number of entity pairs used in correlation = 1770
Distance measure for ORIGINAL distance: Sorensen (Bray-Curtis)

Appendix V. 2014 Reservoir landform plant community indicator species analysis corresponding with Figure 3.14. Refer to Appendix I for codes.

plant code	reservoir	landform	Observed Indicator Value (IV)	IV from Randomized Groups Mean	S.Dev	p
AGROEXA	Aldwell	valley wall	21.3	20.3	4.58	0.3497
EPILCIL	Aldwell	valley wall	26.4	20.7	3.37	0.0602
JUNCBAL	Aldwell	valley wall	28.4	18.1	5.88	0.0808
JUNCEFF	Aldwell	valley wall	45	18.9	5.54	0.0002
CIRSARV	Aldwell	valley wall	47.9	17.6	6.98	0.006
ALNURUB	Aldwell	valley wall	44.5	19.7	5.43	0.0004
MYCEMUR	Aldwell	valley wall	39.3	15.2	7.34	0.0128
RUBUSPE	Aldwell	valley wall	41.2	15.7	7.15	0.015
PHALARU	Aldwell	valley wall	28.8	16.8	6.9	0.056
POPUBALT	Aldwell	valley wall	28.4	21.1	3.32	0.03
SALISIT	Aldwell	valley wall	31	20.7	4.03	0.013
DIGIPUR	Aldwell	valley wall	6	10.8	7.77	0.6757
SONCASP	Aldwell	valley wall	18.1	12.4	6.99	0.1018
HOLCLAN	Aldwell	valley wall	22.1	18.1	6.38	0.198
NOVEGS1	Aldwell	valley wall	16.7	16.7	0.24	1
HYPEPER	Aldwell	valley wall	12.4	12.4	7.39	0.3985
EQUIARV	Aldwell	valley wall	28.6	20.9	4.46	0.0692
CHAMANG	Aldwell	valley wall	20.9	16.6	7.13	0.1864
RUBULEU	Aldwell	valley wall	26	12.4	7.59	0.0432
RANUREP	Aldwell	valley wall	53.4	15.2	7.3	0.003
RUBUPAR	Aldwell	valley wall	21.8	13.3	7.42	0.1062
BROMINE	Aldwell	valley wall	8.1	10.2	7.19	0.4171
SALILUC	Aldwell	valley wall	29.8	14.8	7.6	0.0532
ACERMAC	Aldwell	valley wall	47.4	16.8	7.38	0.0086
HOLODIS	Aldwell	valley wall	33.6	13.9	7.57	0.0308
JUNCBOL	Aldwell	valley wall	22.9	15.1	7.5	0.1218
LOTUCOR	Aldwell	valley wall	44.4	11.2	7.32	0.0088
TSUGHET	Aldwell	valley wall	32.8	14.3	7.46	0.0266
FESTRUB	Aldwell	valley wall	22.2	10.2	7.16	0.137
TOLMMEN	Aldwell	valley wall	22.2	10	7.23	0.1254
IMPACAP	Aldwell	valley wall	44.4	11.1	7.29	0.0096
TRIEBOR	Aldwell	valley wall	11.1	10.1	5.85	0.3463
OSMOBER	Aldwell	valley wall	31.7	11.4	7.4	0.012
PETAFRP	Aldwell	valley wall	16.2	13.1	7.61	0.1854

POA_PAL	Aldwell	valley wall	11.1	10.1	5.85	0.3463
RUBUDIS	Aldwell	valley wall	22.2	10.3	7.33	0.0992
URTIDIO	Aldwell	valley wall	8.2	10.4	7.24	0.4999
VICISP1	Aldwell	valley wall	33.7	12.5	7.67	0.0294
CONYCAN	Aldwell	valley wall	11.1	9.9	5.66	0.3341
GALITRF	Aldwell	valley wall	10	12.4	7.62	0.5369
DICO_SP	Aldwell	valley wall	8.7	10.2	7.32	0.4045
CIRCALP	Aldwell	valley wall	11.1	9.9	5.65	0.3309
MYOSLAX	Aldwell	valley wall	12.8	11.2	7.52	0.3811
RANUOCC	Aldwell	valley wall	11.1	9.9	5.65	0.3309
JUNCMER	Aldwell	valley wall	8.2	12.5	7.04	0.7223
FEST1S1	Aldwell	valley wall	9.1	10.5	7.29	0.4495
EQUISYL	Aldwell	valley wall	11.9	11.3	7.35	0.4293
ASTE1S1	Aldwell	valley wall	11.1	10	5.79	0.3359
LUZUPAR	Aldwell	valley wall	11.1	10	5.79	0.3359
VIOL1S1	Aldwell	valley wall	11.1	10	5.79	0.3359
OMELCER	Aldwell	valley wall	11.1	9.9	5.66	0.3269
CARELEP	Aldwell	terrace	6.2	10	5.69	1
CIRSVUL	Aldwell	terrace	21	15.1	7.5	0.1948
HYPORAD	Aldwell	terrace	35.5	15.7	7.93	0.0238
HESPMAT	Aldwell	terrace	6.2	10	5.69	1
CYTISCO	Aldwell	terrace	12.5	10.2	7.44	0.2819
FRAGVES	Aldwell	terrace	6.2	10	5.69	1
DACTGLO	Aldwell	terrace	15	11.8	7.6	0.2464
PLANLAN	Aldwell	terrace	31.2	12.1	7.97	0.0274
PRUN1S1	Aldwell	terrace	12.5	10.2	7.44	0.2819
VICIHIR	Aldwell	terrace	19.6	12.2	7.8	0.1172
VICISAT	Aldwell	terrace	6.2	10	5.69	1
POA_COM	Aldwell	terrace	10.4	11.3	7.7	0.5101
TRIFPRA	Aldwell	terrace	25	11.4	7.92	0.0368
TRIFREP	Aldwell	terrace	21.4	14.2	7.31	0.1552
VERBTHA	Aldwell	terrace	6.2	10	5.69	1
ARCTMIN	Aldwell	terrace	12.5	10.3	7.47	0.2753
LEUCVUL	Aldwell	terrace	25.4	13.1	7.73	0.0642
GANPMIC	Aldwell	terrace	6.2	10	5.69	1
CREPCAP	Aldwell	terrace	27.5	12.7	7.77	0.0502
ELYMGLAG	Aldwell	terrace	15.6	15.9	7.2	0.4219
AIRACAR	Aldwell	terrace	10	13.9	8.15	0.5971
AGROCAP	Aldwell	terrace	26.7	13.1	7.71	0.0564
LATHLAT	Aldwell	terrace	6.2	10.1	6.07	1
TARAOFF	Aldwell	terrace	19.9	11.8	7.43	0.0904

GERAROB	Aldwell	terrace	12.5	10.2	6.84	0.2677
DICEFOR	Aldwell	terrace	6.2	10	5.79	1
ROSANUT	Aldwell	terrace	6.2	10	5.79	1
RORIISL	Aldwell	terrace	6.2	10	5.79	1
CRATDOU	Aldwell	terrace	6.2	10.1	5.91	1
COLLHET	Aldwell	terrace	8.3	10.6	7.42	0.4383
EPILMIN	Aldwell	terrace	9.7	11	7.58	0.4217
SAGIMAX	Aldwell	terrace	14.7	12.2	7.27	0.3033
CARDOLI	Aldwell	terrace	6.2	10	5.79	1
BROMPAC	Aldwell	terrace	4.1	11.6	8.02	0.9394
BROMSIT	Aldwell	terrace	12.5	10.5	7.12	0.2855
ELEOPAL	Aldwell	terrace	6.2	10.1	5.96	1
ATHYFIL	Aldwell	terrace	40.3	12.2	7.35	0.0138
RUBUURS	Aldwell	terrace	11.1	10.1	5.85	0.3463
CAREOBT	Aldwell	terrace	6.6	10.4	7.38	0.5495
STACCHA	Aldwell	terrace	6.7	12.5	7.11	0.89
MENTARV	Aldwell	terrace	12.5	10	6.89	0.2697
MENTPIP	Aldwell	terrace	6.2	9.8	5.39	1
BARBORT	Aldwell	terrace	6.2	9.9	5.76	1
TARA1S1	Aldwell	terrace	6.2	9.9	5.76	1
SALI1S1	Aldwell	terrace	6.2	9.9	5.76	1
ASPLVER	Aldwell	terrace	6.2	9.9	5.79	1
JUNCART	Aldwell	terrace	21	13	7.41	0.091
BARBVUL	Aldwell	terrace	6.2	9.9	5.58	1
LUZUMUL	Aldwell	terrace	6.2	10	5.78	1
RANU1S1	Aldwell	terrace	6.2	10	5.78	1
AGROSTO	Aldwell	riparian	32.7	18	6.46	0.046
RUMECRI	Aldwell	riparian	41.4	15.8	6.91	0.016
ARTESUK	Aldwell	riparian	15.7	14.7	7.55	0.2937
TRIFDUB	Aldwell	riparian	21.3	10.7	7.18	0.0762
SENEJAC	Aldwell	riparian	32.8	13.6	7.66	0.0328
AGROSP1	Aldwell	riparian	10.7	12.9	7.96	0.5385
BARB1S1	Aldwell	riparian	53.9	11.3	7.39	0.0038
ANAPMAR	Aldwell	riparian	19.7	17	6.34	0.2629
CARESP1	Aldwell	riparian	28.8	17	6.84	0.0552
PSEUMEN	Aldwell	riparian	27.7	19.9	5.91	0.1004
TELLGRA	Aldwell	riparian	18.3	11	7.38	0.1698
OENASAR	Aldwell	riparian	16.5	11.1	7.22	0.2068
ERIOLAN	Aldwell	riparian	21.3	10.3	7.04	0.0964
JUNC1S2	Aldwell	riparian	13.6	12.3	7.34	0.3435
VEROAME	Aldwell	riparian	22.9	14	7.5	0.1336

CARESP2	Aldwell	riparian	26	10.1	7.14	0.0628
JUNCBUF	Aldwell	riparian	65.9	13.4	7.44	0.0014
MIMULEW	Aldwell	riparian	51.3	11.2	7.16	0.0048
TRIF1S1	Aldwell	riparian	75.2	12.6	7.09	0.0004
BRAS_SP	Aldwell	riparian	43	11.9	7.32	0.014
JUNCTEN	Aldwell	riparian	66.7	10.3	7.29	0.0024
EPIL1S1	Aldwell	riparian	27.5	10.1	7.2	0.053
PHLE1S1	Aldwell	riparian	33.3	9.9	5.68	0.047
SENE1S1	Aldwell	riparian	33.3	9.9	5.68	0.047
CAREDEW	Mills	valley wall	18	16.2	7.15	0.3217
ACHIMIL	Mills	valley wall	5.8	13.9	8.3	0.9618
DESCELO	Mills	valley wall	15.2	20.3	4.65	0.8934
SENEVUL	Mills	valley wall	10.1	13.5	7.55	0.6233
GLYCELA	Mills	valley wall	6.2	10.1	7.21	0.7361
CARESTI	Mills	valley wall	16.5	14.2	7.34	0.2557
THUJPLI	Mills	valley wall	11.6	14.2	8.36	0.5251
JUNCACU	Mills	valley wall	18.3	12.2	7.13	0.0946
GALIAPA	Mills	valley wall	11.5	10.7	7.62	0.3367
PLANMAJ	Mills	valley wall	6.2	10.1	7.29	0.7367
STELCAL	Mills	valley wall	20.1	11.8	7.52	0.0652
RUMEACE	Mills	valley wall	8.7	12.1	7.83	0.6229
CLAYPAR	Mills	valley wall	12.1	11.4	7.34	0.4253
SOILCAS	Mills	valley wall	10	10.1	5.91	0.5079
ERIGPHI	Mills	valley wall	10	10.1	5.91	0.5079
POLYGLY	Mills	valley wall	10	10.1	5.91	0.5079
VICIAME	Mills	valley wall	10	10.1	5.91	0.5079
PRUNEMA	Mills	valley wall	4.3	10.8	7.46	0.9466
STELCRI	Mills	valley wall	20	10.2	7.39	0.1596
GYMNDRY	Mills	valley wall	10	10	5.82	0.5019
RIBELAC	Mills	valley wall	10	10	5.82	0.5019
GALI1S1	Mills	valley wall	7.4	10.3	7.32	0.5741
POA_PRA	Mills	valley wall	10	10	5.87	0.4923
LAPSCOM	Mills	terrace	3.8	10.1	7.14	1
EQUIHYE	Mills	terrace	3.8	10	7.14	1
CLAYNSIB	Mills	terrace	7.1	9.9	5.69	0.7327
SEDU1S1	Mills	terrace	7.1	10	5.81	0.7315
COLL1S1	Mills	terrace	7.1	10	6.02	0.7181
CAREPAC	Mills	terrace	14.3	10.4	7.57	0.2148
COLLGRA	Mills	terrace	7.1	10	5.87	0.7369
AIRA1S1	Mills	terrace	7.1	10	5.83	0.7291
HIERALB	Mills	terrace	7.1	10.1	6.12	0.7299

SENESYL	Mills	riparian	18.4	16.2	6.65	0.2959
EPILBRA	Mills	riparian	22.1	19.6	5.74	0.2452
CERAARV	Mills	riparian	8.7	13.9	7.5	0.79
POA_ANN	Mills	riparian	30.9	11.8	7.38	0.0198
VULPMYU	Mills	riparian	10.9	12.2	8.3	0.4453
POA_TRV	Mills	riparian	4.9	10.9	7.38	0.8276
PRUNVUL	Mills	riparian	8.3	10.1	7.22	0.3465
FRAGVIR	Mills	riparian	8.3	10.3	7.49	0.3615
ASTE_SP	Mills	riparian	8.3	10.4	7.62	0.3627
EIROLAN	Mills	riparian	17.1	12.1	7.46	0.172
JUNCENS	Mills	riparian	18.7	10.6	7.43	0.1628
CAREPHA	Mills	riparian	6.7	10.4	7.47	0.6507
AGOSAUR	Mills	riparian	12.5	10	5.94	0.1778
PRUMEMA	Mills	riparian	12.5	10	5.94	0.1778
CARESIT	Mills	riparian	12.5	10	5.94	0.1778
SEDUSPA	Mills	riparian	12.1	11.3	7.74	0.4075
AIRAPRA	Mills	riparian	9.1	10.2	7.38	0.3437
EPLICIL	Mills	riparian	12.5	10	5.77	0.1874
ALPOGEN	Mills	riparian	12.5	10	5.77	0.1874
MIMU1S1	Mills	riparian	12.5	10.1	6.04	0.195
CLAYSIB	Mills	riparian	6.9	10.2	7.25	0.5445
MIMUGUT	Mills	riparian	6.9	10.1	7.26	0.5525
LUPIRIV	Mills	riparian	31.5	11.1	7.21	0.0124
BROMRAC	Mills	riparian	34.2	11.3	7.36	0.012
JUNCSUP	Mills	riparian	12.5	9.9	5.77	0.1842
SALISTI	Mills	riparian	12.5	9.9	5.77	0.1842
ALOPAEQ	Mills	riparian	12.5	9.9	5.77	0.1842
BROM1S1	Mills	riparian	12.5	10	5.79	0.1818
FESTOCC	Mills	riparian	12.5	10	5.79	0.1818
POA_1S2	Mills	riparian	25	10	7.18	0.0972
SPERCAN	Mills	riparian	12.5	10	5.75	0.1764

Appendix VI. Variance explained (as r^2 values) by the axes in each of the NMS ordination. Total variance explained by each ordination can be found in the cumulative column. Corresponds with Figure 3.14.

Axis	R Squared Increment	Cumulative
1	.574	.574
2	.205	.779

Increment and cumulative R-squared were adjusted for any lack of orthogonality of axes.

Axis pair	r	Orthogonality, % = $100(1-r^2)$
1 vs 2	-0.022	100.0

Number of entities = 60
Number of entity pairs used in correlation = 1770
Distance measure for ORIGINAL distance: Sorensen (Bray-Curtis)

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EDUCATION

- B.S. Natural Resource Sciences (*Cum Laude*), Washington State University, Pullman, WA

RESEARCH EXPERIENCE

- 20-28August 2014 Contracted to U.S. Geological Survey, Port Angeles, WA
- 06/July-07/August 2014 Elwha River Summer Field Crew, Eastern Washington University
- 06/July-07/August 2014 US Geological Survey and Lower Elwha Klallam Tribe Ungulate Browse Study, Port Angeles, WA
- 07/July-16/August 2013 Elwha River Summer Field Crew, Eastern Washington University
- 2010-2013 Wild Ungulate Facility Work Study, Washington State University

PROFESSIONAL EXPERIENCE

- 15/May-05/July 2013 Field Technician, Nez Perce Soil and Water Conservation District, Culdesac, ID
- 11/May-06/July 2012 Summer Internship, Wolf Hollow Wildlife Rehabilitation Center, Friday Harbor, WA
- 2004-2009 Aviation Structural Mechanic Second Class, United States Navy, Oak Harbor, WA

VOLUNTEER EXPERIENCE

- 2010-2013 Washington State University Raptor Club, Washington State University, Pullman, WA
- 2015 National Conference for Undergraduate Research, Eastern Washington University, Cheney, WA

RESEARCH PRESENTATIONS

Oral Presentations

Schuster, J. May 2014. Vegetation colonization following dam removal on the Elwha River, WA. Eastern Washington University Student Research and Creative Works Symposium, Cheney, WA.

Schuster, J. April 2015. Vegetation Colonization within Drained Impoundments Following Dam Removal on the Elwha River, Washington. Graduate Research and Creative Arts Symposium, Cheney, WA.

Poster Presentations

Schuster, J. and R. L. Brown. October 2014. Vegetation colonization following dam removal on the Elwha River, Washington. Society for Ecological Restoration Regional Conference, Redmond, OR.

Schuster, J. and R. L. Brown. December 2014. Reservoir Vegetation Colonization Following Dam Removal on the Elwha River, Washington. Eastern Washington University Biology Graduate Student Research Seminar, Cheney, WA.

TEACHING ASSISTANTSHIPS, EASTERN WASHINGTON UNIVERSITY

2015-Animal Physiology (BioL 490), Introduction to Environmental Science (ENVS 100), Biology I (BioL 171)

2014-Biology II (BioL 172, 2 sections), Biological Investigation (BioL 270), Field Ecology (BioL 490), Animal Physiology (BioL 490)

2013-Biology II (BioL 172), Ecology Laboratory (Biol 441)

SCHOLARSHIPS AND AWARDS

2013-2015	Graduate Service Appointment, Eastern Washington University
2012-2013	Blackie Schons Scholarship, Frances Premo Memorial Scholarship, Washington State University
2011-2012	Elmer and Mabel Kegel Memorial Scholarship, Washington State University
2011	Pass with Distinction Junior Writing Portfolio, Washington State University
2010-2013	Washington State University's President's Honor Roll
2010	Navy and Marine Corps Achievement Medal
2007	Navy Good Conduct Medal

FELLOWSHIPS AWARDED

2014	J. Herman, Jean Swartz, Frances and William P. Werschler Graduate Fellowship, Eastern Washington University
2013	Biology Graduate Fellowship, Eastern Washington University

GRANTS AWARDED

2014	Eastern Washington University Biology Department Mini Research Grant
2014	Eastern Washington University Biology Department Graduate Student Travel Grant